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DEVELOPMENT OF PASSIVE DIVER THERMAL PROTECTION SYSTEM

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The development of the US Navy Passive Diver Thermal Protection System, designed to satisfy a majority of the air mode thermal protection requirements of fleet diving activities in cold water, is described. The requirements, the evolution of system design, the development and test of the various prototypes, and the system operational and performance evaluations are discussed. The final system demonstrated its ability to maintain a resting diver within acceptable thermal limits for 6 hours in 4.5°C water. The protection system allows

sufficient mobility to allow the diver to engage in typical special warfare activities such as helicopter cast and recovery, parachuting, boat cast and recovery, and long surface and underwater swims.

SUMMARY

Cold water impairs diver performance and significantly reduces dive duration. However, mission scenarios for the military diver often preclude use of existing tethered active heating systems. Accordingly, the Naval Coastal Systems Center (NCSC) has undertaken the development of diver thermal protection (DTP) equipment to satisfy the requirements of Navy and Marine Corps cold water diver/swimmer applications. This report describes development of an insulated passive garment system which provides thermal protection to divers using either air or nitrogen-oxygen breathing gas mixtures.

Initial efforts focused on establishing broad operational requirements which defined diver performance and limits of thermal stress. On the basis of these criteria, evaluations of commercially available diver thermal protection equipment were made, and a variety of outergarment and undergarment materials were tested. These tests confirmed the need for a diver thermal protection system capable of supporting long-duration missions, and established the variable volume coated fabric dry suit/undergarment as the basic system design concept.

Prior to initiating the engineering development program, system performance thresholds and goals were established based on two Navy Decision Coordinating Papers (NDCPs), data from commercial equipment evaluations, and inputs from a refined analytical model. On this basis, a system design philosophy was formulated which addressed six major development areas: a dry-suit outergarment, thermal undergarment, dry gloves, buoyancy controls, a weight distribution system, and a urine collection system.

Engineering development and tests were then begun, focusing on each of the six major design areas. Various candidate outergarment, undergarment, and glove designs were evaluated, and a number of alternative configurations were considered for the glove, weight distribution system, and urine collection system before a total system configuration was developed and subjected to operational tests.

The thermal performance of manned Passive Diver Thermal Protection System (PDTPS) prototypes was evaluated in instrumented tests conducted at the Navy Experimental Diving Unit (NEDU). The system satisfied the thermal performance requirements by demonstrating the ability to maintain a diver in an acceptable thermal status for 6 hours in water of approximately 40°F.

Subsequent operational tests of the PDTPS were conducted in the field at Brunswick, Maine; New London, Connecticut; Whidbey Island, Washington; and Kodiak Island, Alaska. All tests used fleet divers in operational scenarios.

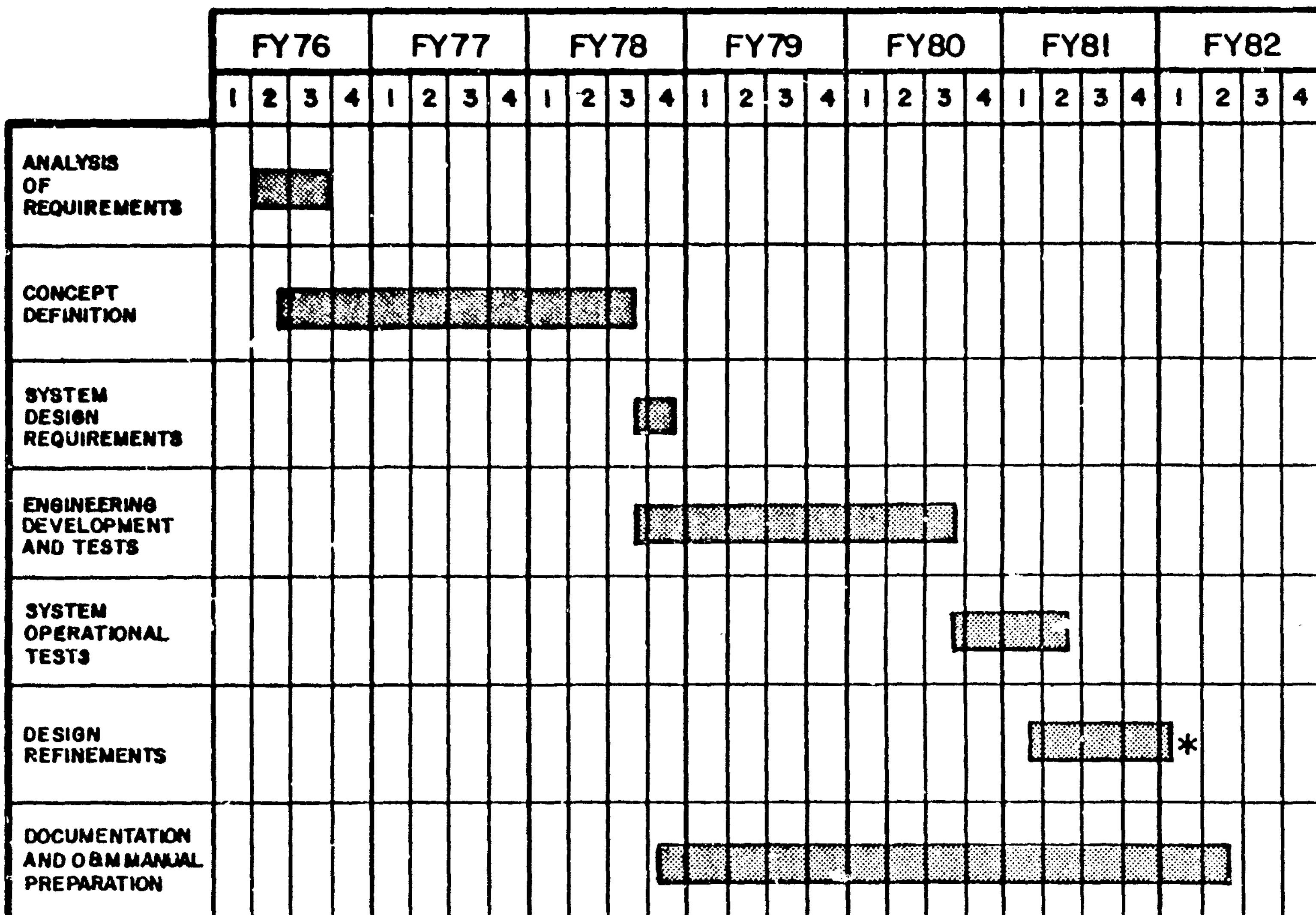
The Whidbey and Kodiak exercises, in particular, focused on SDV operations. The PDTPS was also subjected to range-of-motion and rapid compression/decompression tests at NEDU, Panama City.

Based on diver comments and results of operational tests, two remaining minor problems were identified. Appropriate modifications were incorporated into the suit, then tested and evaluated at NEDU to arrive at the final system configuration.

The PDTPS is recommended specifically for long-duration cold-water missions. Tests to further evaluate additional diving applications for the system are scheduled to begin early in 1982. It is also recommended that use of a modified thermal undergarment by divers performing land operations be pursued and evaluated.

A schedule of the PDTPS development program is depicted in the graph.

PASSIVE DIVER THERMAL PROTECTION SYSTEM SCHEDULE OF SYSTEM DEVELOPMENT



* INITIATE PRODUCTION CYCLE

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INTRODUCTION

BACKGROUND

Inadequate protection from cold water can severely limit a military diver's ability to accomplish his mission. Advances in diving life support systems now permit the military diver to conduct long duration missions in warm water. However, in cold water a diver's physical and mental performance can be impaired and the length of a safe dive is significantly reduced. This is a particularly severe limitation for activities peculiar to the military diver since the location and clandestine nature of an operation often preclude surface support and impose constraints on diver equipment.

The Naval Coastal Systems Center (NCSC) has undertaken the development of diver thermal protection (DTP) equipment to satisfy the requirements of Navy and Marine Corps cold water diver/swimmer applications. Due to extreme differences in thermal protection required for divers using air and those using heliox mixtures, a two-part development program was established at the outset to satisfy these two needs:

1. An insulated passive garment system to provide thermal protecton to divers using air or nitrogen-oxygen breathing gas mixtures. An insulated garment system is relatively simple compared to an active heating system and is preferable when conditions permit.

2. Supplemental heating systems necessary for thermal protection of divers using heliox mixtures to meet their thermal protection needs. The development of such active systems is underway at NCSC.

Providing adequate thermal insulation to the diver's body is difficult because of the underwater operating environment. In a gaseous atmosphere, the insulation provided by clothing is largely due to trapped gas. In water, however, any insulating layer of gas is lost. Moreover, water has a thermal conductivity nearly 25 times that of air. The heat capacity of water (product of density and specific heat) is approximately 3500 times that of air. Consequently, body heat is lost much faster in water than in air of the same temperature.

Development of thermal protection equipment for divers has assumed many directions; however, the concepts of a wet suit or a dry suit are basic to the design of most systems.

The dry suit concept is not new to the Navy. A rubberized canvas dry suit has been used with the Mark 5 hard hat diving system for many years.

During World War II, combat swimmers used dry suits made of varying thicknesses of rubber. In both cases, because the dry suit itself provided little insulation, the degree of thermal protection provided was a function of the clothing worn underneath the suit.

The wet suit was introduced in the early 1950s with the development of tight-fitting suits made of a closed-cell foam neoprene rubber. Each of the closed cells in foam rubber entrap a small quantity of gas. The foam rubber acts as a thermal insulator because there is no convection between the closed cells; and, if the entrapped gas is air, there is little thermal conduction within cells. These wet suits are designed to permit water to fill any space between the suit and the diver's skin. Free flow of this water is restricted, thus allowing body heat to warm the small quantity of water present. The foam rubber suit insulates this small quantity of water and slows loss of heat to the environment. The wet suit also eliminates problems of leakage and suit squeeze associated with the dry suit.

Wet suits will give effective, reliable thermal protection for short duration shallow-depth diving, even in very cold water. The wet suit today is the most widely used thermal protection garment for commercial, military, and sport diving when self-contained breathing apparatus is used.

The main drawback of a conventional wet suit is the loss in insulation value resulting from compression of the gas bubbles within the neoprene foam under hydrostatic pressure. For example, a 1/4-inch wet suit at a depth of 33 feet (10 metres) loses approximately half of its thermal insulation and at 100 feet (30 metres) offers minimal thermal protection to the diver. The fact that water normally becomes increasingly colder at greater depths further compounds the problem.

Dry suits offer a substantial improvement in thermal protection to the diver, particularly when the suit is inflated with air, since the insulating effectiveness of any garment primarily depends on entrapped air. Dry suits also permit use of thermal undergarments which further increase diver warmth. However, as with wet suits, dry suits made of foam neoprene exhibit a reduction in thermal resistance at increased depths; and a diver must rely on the insulation provided by undergarments. However, thick undergarments which must be worn to compensate for the effects of compression at increased depths result in bulky, overly warm garments at shallow depths.

Dry suits constructed of thin, rubber-coated fabrics offer nearly uniform insulation qualities at any depth provided the type of suit inflation gas is unchanged. The thin dry suit offers little insulation by itself; but when used in conjunction with a good thermal undergarment, a diver may experience nearly uniform thermal comfort as he descends and later surfaces. This garment also minimizes suit buoyancy changes which occur with foam dry suits as depth is varied.

This latter dry suit concept served as the basis for the NCSC development of a passive DTP system. A brief description of that system follows.

PASSIVE DTP SYSTEM DESCRIPTION

The Passive DTP System (PDTPS) developed at NCSC is a modular, variable-volume dry suit system. A flexible, watertight outergarment keeps the diver dry. Inlet and exhaust valves are used to control the suit inflation level. Thermal insulation is provided by insulating underwear which is worn over a cotton long john comfort layer and socks. Dry gloves with insulating liners keep the diver's hands warm. The basic system components are shown in Figure 1.

Outergarment

The outergarment is made from a foam neoprene elastomer specially processed to permanently eliminate the gas-filled cell structure found in wet suits. A knitted nylon fabric is bonded to both sides of the material. A hood, boots, neck seal, wrist seals, and wrist rings are integral to the outergarment. The outergarment is equipped with calf and thigh restraints, ankle straps, and weight pockets. A watertight zipper across the shoulders allows diver entry through the back of the suit. Front and back views of a diver outfitted in the PDTPS are shown in Figures 2A and 2B.

Inflation gas inlet and exhaust valves penetrate the outergarment. These permit the diver to control the amount of inflation gas in his suit, allowing control over his suit buoyancy and partial control over his suit insulation.

Thermal Undergarment

The undergarment provides most of the system insulation and consists of three components: jacket, pants, and thermal boots. The insulating material is a microfibrous polyolefin batt. This material insulates well for its low weight and bulk and is relatively compression and moisture resistant. Nylon taffeta is used as an outer layer, and neoprene-coated nylon taffeta is used as the inner layer. The inner coating forms a moisture- and vapor-resistant barrier. The thermal undergarment is worn over a comfort liner of long johns and socks (Figures 3 and 4).

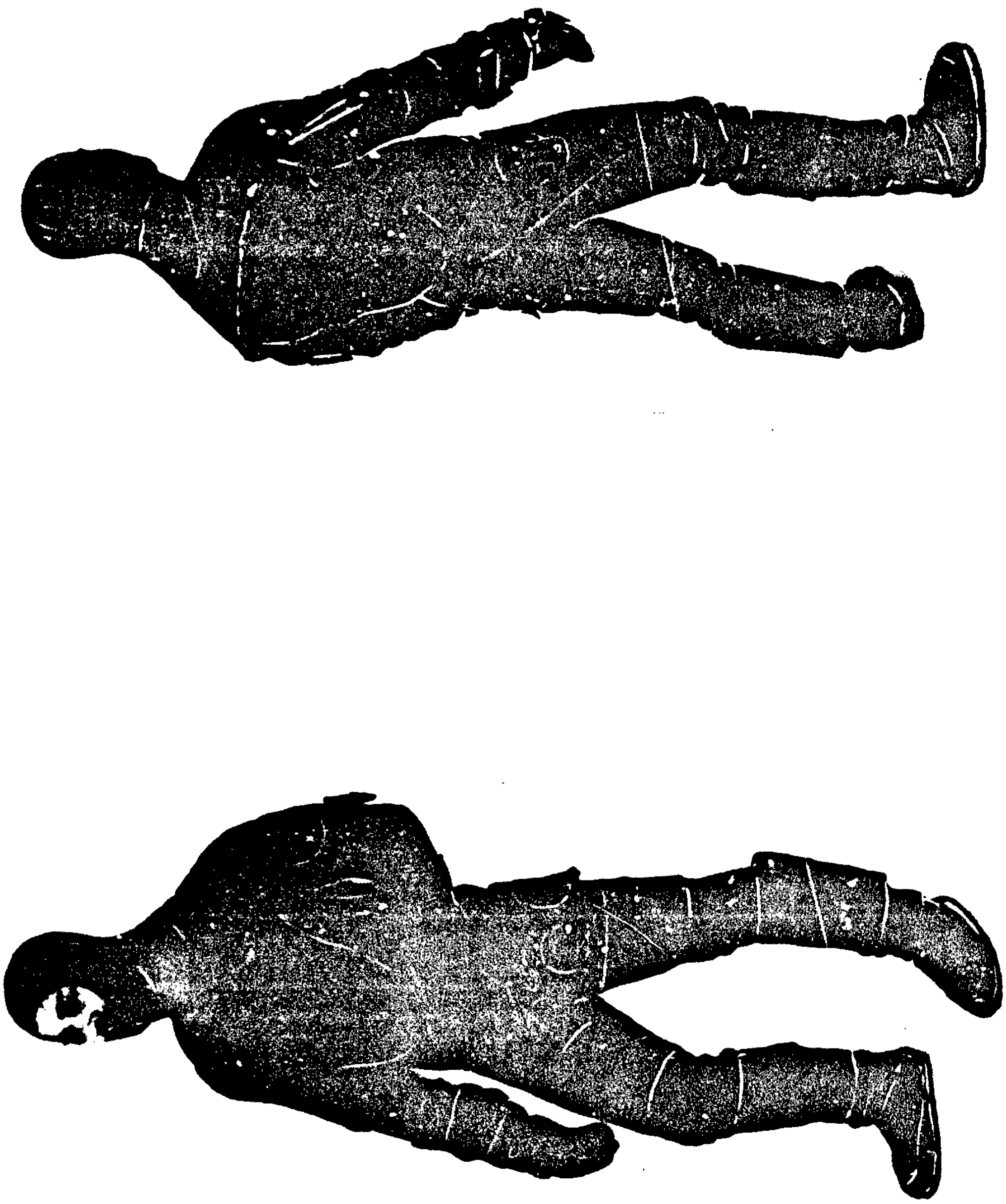
Dry Gloves

The dry gloves seal onto the outergarment at the wrist rings where they are secured with an elastic strap. Each glove has a thermal liner insulated with a material similar to that used in the undergarment (Figures 5 and 6.)

Other Components

Other components in the NCSC-developed PDTPS are shown in Figures 7, 8, 9, and 10. They include an independent suit inflation source, inflation hoses, a Diver Urine Collection System (DUCS) for long duration missions, fin guards to prevent loss of swim fins, and other optional accessories including a thermally insulated cap and a cold weather face protector.

FIGURE 1. BASIC COMPONENTS - PASSIVE DIVER THERMAL PROTECTION SYSTEM



A. FRONT

B. BACK

FIGURE 2. DIVER WEARING PDTPS

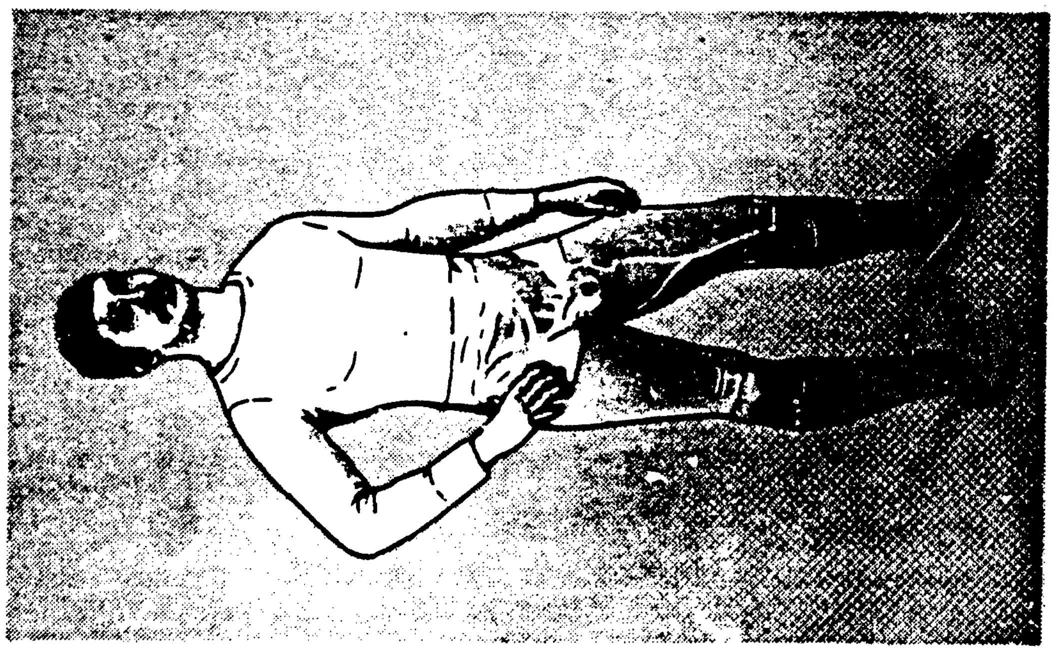


FIGURE 3. DIVER IN COMFORT LINER AND DUCS

FIGURE 4. DIVER WEARING THERMAL UNDERGARMENT

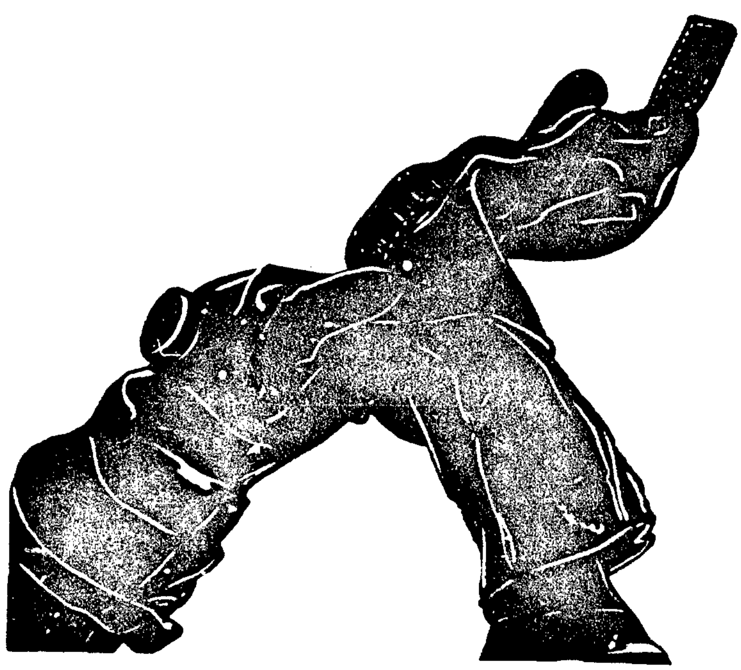


FIGURE 5. DIVER DONNING GLOVE

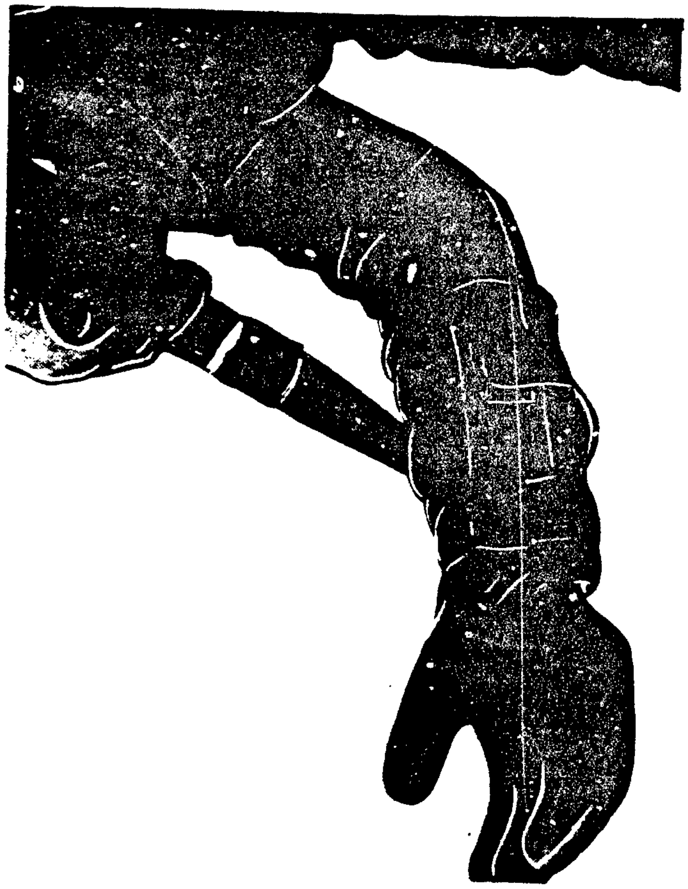


FIGURE 6. DIVER SEALING GLOVE WITH STRAP, SHOWING HOOK-AND-PILE CLOSURE

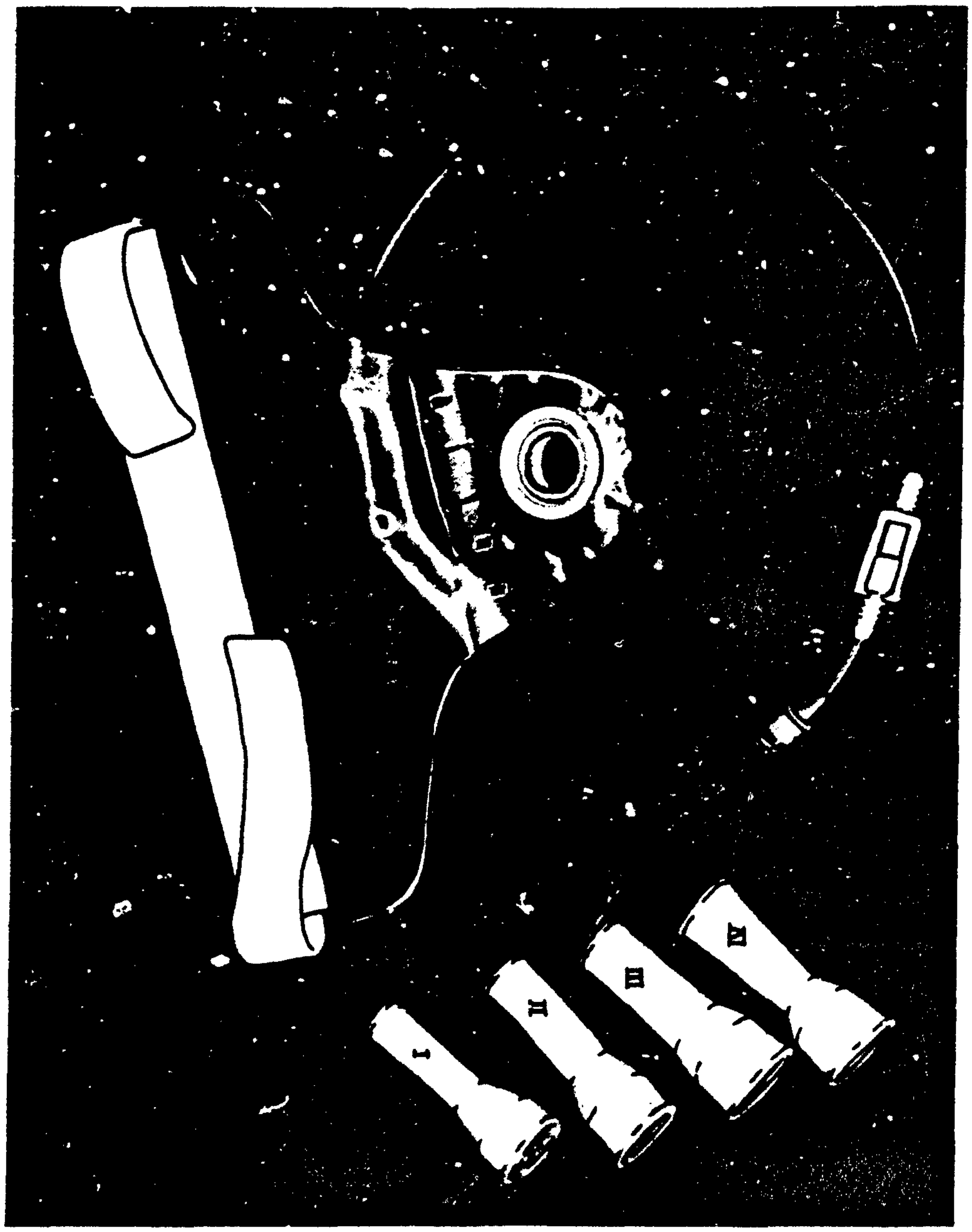


FIGURE 7. DIVER URINE COLLECTION SYSTEM (DUCS)

FIGURE 8. THERMAL CAP

FIGURE 9. FIN GUARDS

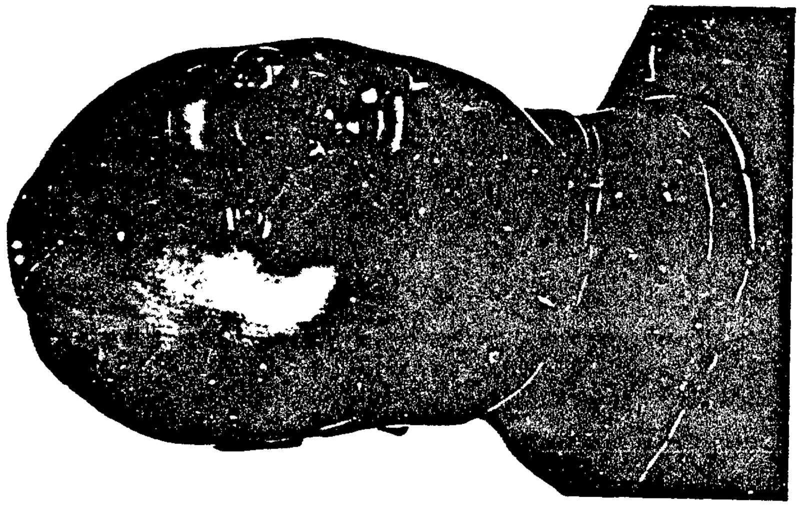


FIGURE 10. COLD WEATHER FACE PROTECTOR

PERFORMANCE REQUIREMENTS

Initial efforts in the development of the PDTPS focused on the identification of diver thermal protection needs and thermal limits of the operational diver. The Navy diver's activities range from the support of salvage operations to the clandestine attack of enemy marine and shore assets. Operational requirements and similar documents were reviewed to identify the salient characteristics pertinent to thermal protection among the various missions. Some of the factors considered were diver activity level (metabolic rate), dive depth and duration, breathing gas composition, environmental characteristics, life support systems and other mission-related equipment, and the actual tasks the diver must perform.

Along with the operational requirements, it was necessary to establish criteria to define the thermal limits for a diver to accomplish the mission objective and return safely. A panel of experts under the auspices of the Bureau of Medicine and Surgery (BUMED) developed a set of criteria in July 1976 (updated in September 1980) (Table 1).

These criteria formed a basis for the study of existing diver thermal protection equipment and for an engineering development program with broad operational requirements defining what the diver must perform and the allowed limits of thermal stress.

TABLE 1

PHYSIOLOGICAL DESIGN GOALS FOR THERMAL PROTECTION OF DIVERS

1. Maximum net body heat loss (change in enthalpy) of 3 kcal per kg of body weight.

2. Core temperature not lower than 36°C (96.8°F), or a 1°C (1.8°F) drop, whichever is lower.

3. Mean skin temperature not lower than 25°C (77°F), and no individual skin temperature lower than 20°C (68°F), except that of the hand, which may go as low as 15°C (59°F).

NOTE: THESE GOALS WERE TAKEN FROM REFERENCE 1.

[1]Naval Medical Research Development Command Report, "Physiological Design Goals for Thermal Protection of Divers," prepared by Webb Associates, Yellow Springs, Ohio, presented at a conference at Bethesda, Maryland, 5 September 1980.

EVOLUTION OF SYSTEM DESIGN

Efforts in the development program during the phases prior to full-scale development and testing included the evaluation of commercially available thermal protection diving equipment, tests and analysis of a variety of outergarment and undergarment materials, and establishment of specific functional and operational design criteria.

COMMERCIAL EQUIPMENT EVALUATION

An investigation of commercially available diver thermal protection equipment was made to determine those items which could be used as is, those which were acceptable with minor modifications, and those which required further development. These initial investigations produced a substantial data base in the form of commercial literature, scientific reports, and commercial and military test reports. This data base was used in the formulation of a system baseline.

Thermal protection diver dress systems can be divided into three basic categories: wet suits, variable volume dry suits, and free-flooding hot-water suits. Other systems are being developed but are not in wide use. From available information, estimates were made of the submerged time duration permitted by those systems in cold water and surface support requirements (Table 2). From these estimates, it was concluded that (1) wet suits and free-flooding hot-water suits should be used by the Navy diver where environmental conditions, availability of surface support, and mission times permit and (2) the emphasis of the Navy's development program should be the variable-volume dry suit system.

TABLE 2

ESTIMATED TIME IN COLD WATER WITH STATE-OF-THE-ART DIVING DRESS

Diving Dress	Shallow (<10 m)	Deep (>30 m)	Surface Support Required
Wet suit	1 - 3 hours	1/2 - 1 hour	None
Open-circuit hot-water suit	Not limiting	Not limiting with heated breathing gas	Substantial
Variable-volume dry suit with thermal underwear	4 - 8 hours	1 - 3 hours	None

Water temperature approximately 40°F (4.4°C)

Seven commercially available dry suits and five types of underwear were obtained for comparative testing. The equipment had obvious differences in design and construction, and any information from testing was used to determine the criticality of these differences. The Navy Clothing and Textile Research Facility (NCTRF) had inspected each dry suit model and recorded observations on materials, construction, seam types, closures, patterns, and designs.[2] The suits were donned and doffed, but no thermal tests were made. NCTRF evaluations rated the suits and concluded that all suits tested had deficiencies or disadvantages and that a superior dry suit could be designed using the best features of several garments. Recommendations reflected special concern for seam construction and zipper location.

Three sizes of each of the seven dry suits were tested for comparative mobility by the Department of Kinesiology, University of California, Los Angeles.[3] Experienced divers evaluated the range of motion which the suits provided by making 18 different movements. The 18 movements were chosen to represent body movements in underwater work. The movements were measured directly with the aid of an underwater electrogoniometer and indirectly using closed-circuit television and video tape recording. Data were analyzed, and each suit was ranked based on the overall range of motion. In general, foam suits rated better than commercially available elastomer-coated fabric suits. Suits with horizontal back entry closures consistently ranked high.

Divers at NCSC performed subjective evaluations of the seven dry suits.[4] Six divers tested the suits in cold water in 94 individual dives. The suits were tested alone and with various combinations of undergarments. Divers completed evaluation forms following each dive, and a summary evaluation was conducted at the end of the testing program. Each suit was ranked. Favorable and unfavorable characteristics of the suits were listed and tested, and development recommendations were made. The important areas of consideration in design and selection of dry suits were: dryness; relative convenience and mobility provided by zipper location; watertight integrity and reliability of wrist and neck seals; and suit fit, which affects mobility, swimmability, chafing, suit squeeze, and comfort.

The seven dry suit models and six different thermal under garments were tested by the US Army Research Institute of Environmental Medicine (ARIEM)

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[2]Naval Clothing and Textile Research Facility Letter Report, "Inspection of Commercial Dry-Type Diver's Suits," for Work Request No. N61331-76-WR-T-0002, November 1976.

[3]Naval Coastal Systems Center Technical Memorandum TM 234-78, "Comparative Mobility in Various Dry Suits," prepared by the Department of Kenesiology, University of California, Los Angeles, August 1978.

[4]Naval Coastal Systems Center Technical Memorandum TM 241-78, "Human Engineering Evaluation of Dry Suits for Navy Use," by J. F. Wattenbarger and LT J. Brady, October 1978.

for thermal characteristics.[5] The copper manikin used in these tests is a life-sized, anthropomorphic copper shell wired internally and supported by a control unit with electric power for heating. The manikin thermally simulates a human being. It is instrumented to detect skin temperatures which can be maintained through application of power to the internal heater. When the manikin is dressed, measurement of power used to maintain skin temperatures allows calculation of the insulation value of the garment system being evaluated.

Insulation values of the seven dry suit models were determined with the manikin standing either in still air (approximately 0.1 m/sec air motion) or immersed to the neck in water. Four of these suits were also studied in combination with the various undergarments. Finally, insulation values in air were obtained on the undergarment items alone. All values were compared to those obtained with a nude manikin.

The copper manikin tests permitted empirical and subjective evaluations of the dry suit systems. There was wide variation in the amount of insulation that dry suits and dry suit/undergarment ensembles provided. All suits or ensembles had a lower insulation value immersed in water than in air; the loss in insulation in all cases was greater than the loss in boundary layer insulation of the nude manikin. Examination of materials led to the conclusion that losses of intrinsic suit or ensemble insulations were due to hydrostatic pressure differences between the head and feet. Hydrostatic pressure reduced thicknesses of air space between the suit and manikin and often compressed the suit or undergarment insulation material.

The copper manikin tests found that none of the dry suits or dry suit/undergarment ensembles had enough insulation to meet required thermal criteria and performance goals.

NCSC and ARIEM also used the copper manikin to test three dry suit models in combination with five types of undergarments under hyperbaric conditions.[6] Ten configurations were tested to simulated depths of 16 ata (atmospheres absolute) with nitrogen and helium used as suit inflation gases. Prior to these tests in March 1978, NCSC developed an analytical model for predicting the thermal properties of diving suit materials at surface and hyperbaric conditions.[7] The test results differed slightly from predicted values, requiring modification of the assumptions used in the analytical thermal model.

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[5]US Army Research Institute of Environmental Medicine Report No. T 1/81, "Thermal Protection of Commercial Dry Suit Diving Systems," by James E. Bogart, John R. Breckenridge, and Ralph F. Goldman, Ph.D., January 1981.

[6]Wattenbarger, J. F. and Breckenridge, J. R., "Dry Suit Insulation Characteristics Under Hyperbaric Conditions," American Society of Mechanical Engineers Publication OED-Volume 6, pages 101-116, 1978.

[7]Nuckols, M. L., "Thermal Considerations in the Design of Diver's Suits," American Society of Mechanical Engineers Publication OED-Volume 6, pages 33-99, 1978.

The tests, as predicted, showed significantly less insulation at all depths when helium was used as the suit system's inflation gas. In general, all neoprene foam dry suit/undergarment ensembles had a reduction of insulation with depth, with greatest insulation loss occurring in the first 4 ata of depth. Coated-fabric dry suit/undergarment ensembles showed no reduction in insulation with depth.

The testing and evaluation of commercial equipment revealed the need for an engineering development program to obtain equipment to protect divers in cold water for missions up to 6 hours. This commercial equipment evaluation also demonstrated the most successful approaches to thermal protection.

SYSTEM DESIGN REQUIREMENTS

For the engineering development program, more specific requirements and limitations had to be established to ensure that the equipment developed would meet the needs of the military diver. The system must allow a diver to conduct military missions without degrading survivability or increasing vulnerability.

To conduct a systematic engineering development program, functional criteria and specific operational requirements were established during the initial phases of the activity. A review of current Navy diving requirements was used to establish performance thresholds and goals for a passive thermal protection system (Table 3). Data collected during the testing of commercial equipment and inputs from the refined analytical model were also used to establish those thresholds and goals.

From these requirements, specific operational characteristics were also established. It was determined that to be mission-useful, a thermal protection system should meet certain operational criteria and be capable of withstanding the stresses involved in various military evolutions.

1. System should be capable of fresh water or salt water use.

2. System should be capable of storage in marine environments: long-term (10 years) in temperatures from 0°F to 140°F; and short-term exposures (4 hours) in direct sunlight at -40°F to 140°F.

3. System should be capable of withstanding abrasion encountered in normal service use.

4. While wearing the system, a diver should be capable of climbing unassisted through a 24-inch cylindrical trunk 30 inches deep.

5. Divers wearing the system should be able to operate the various mechanisms involved in using a 24-inch hatch, adapt to pressure changes, parachute jump and withstand water impact and associated landing efforts, climb a rope ladder beneath a hovering helicopter, swim long distances, withstand stresses involved in cast and recovery, and perform long duration underwater missions.

TABLE 3

REQUIRED PERFORMANCE CHARACTERISTICS OF A DRY SUIT

Requirement	Threshold	Goal
Insulation equivalence	1.0 clo*	1.2 clo*
Net body heat loss	3 kcal/kg of body weight	3 kcal/kg of body weight
Range of motion (% of nude mobility)	85%	85%
Dive duration**	6 hours	6 hours
Low temperature limit	40°F (4.4°C)	29°F (-1.7°C)
Maximum depth	200 fsw (61.0 msw)	300 fsw (91.4 msw)
Maximum descent rate	30 ft/min (9.1 m/min)	60 ft/min 18.3 m/min)
Maximum ascent rate	60 ft/min (18.3 m/min)	60 ft/min (18.3 m/min)
Life support reliability	97.5%	97.5%
Mission support reliability	90%	90%

These performance characteristics apply only when air or a mixture of nitrogen and oxygen is used for suit inflation.

*Clo is a measure of insulation such that 1 clo = 0.18 m^2-hr-°C/kcal. One clo of insulation will maintain normal skin temperature of the human body when heat production is 50 kcal per square metre per hour (normal heat production of a man at rest), air temperature is 70°F (21.1°C) and the air is still. A standard 0.25-inch wet suit has an approximate value of 0.75 clo water at the surface.

**When the diver sustains a moderate level of physical activity.

6. The mean time to repair (MTTR) at the organizational level should be no greater than 1 hour. The mean time to fault locate (MTFL) should be no greater than 30 minutes.

7. The operational availability of the system should be at least 0.75 when maintained according to the system Operation and Maintenance (O&M) Manual. Reaction time, when a mission is randomly ordered, will be no greater than 15 minutes. Turnaround time, the time between successive dives, should be no greater than 20 minutes.

8. The system should provide the required thermal protection when operated with open-circuit SCUBA, MK 6, MK 15, MK 16, MK 1 bandmask diving system, Jack Browne Mask, and various diver submersibles.

9. The system should be simple enough to require only minimal training for use by qualified divers.

10. The system should be capable of meeting the electromagnetic signature requirements of MIL-M-19595C(OS).

These functional and operational performance criteria were incorporated into a development specification following the testing of available commercial thermal protection equipment. These criteria also were used to formulate the system design philosophy.

SYSTEM DESIGN PHILOSOPHY

Using established system performance and design requirements as well as information derived from literature research, commercial equipment evaluations, and an analytical thermal model, a system design and development philosophy was formulated.

The system design philosophy for a passive thermal protection system covered six major development areas.

Dry Suit Outergarment

A variable volume dry suit design was selected. All information available indicated dry suit systems could provide more thermal insulation than wet suits. Further development of wet suits was not indicated because wet suit technology is well developed.

For a dry suit to provide good thermal protection, it is important that the diver remain dry. Since nearly all of the commercial suits tested had leaks, special efforts were made in the development of improved dry suit seals and entry closures.

It was determined that the outer garment should be constructed of an elastomer-coated fabric or other noncompressible material. The material itself would provide little insulation, with a thermal undergarment providing the major portion of the system insulation. This design would provide a constant insulation over a range of depths. In addition, the reduction of buoyancy with depth exhibited by the compression of the closed-cell foams is eliminated, thereby simplifying buoyancy control.

Thermal Undergarment

A thermal undergarment would provide the primary system thermal insulation. The analytical model indicated that for the total passive system, an inherent insulation value of approximately 1.0 to 1.5 clo would be adequate for most diving applications.

Basic improvements in diver underwear were required for a successful passive thermal protection system. The compressibility of nearly all conventional diver underwear tested allowed more than half of their insulation value to be lost when the diver entered the water. The hydrostatic pressure differential between the diver's chest and feet when the diver is in an upright position reduces the thickness of gas space between the suit and diver and compresses the underwear. This effect reduces the insulation value of the entire ensemble, particularly in the leg and foot portions; this explains why the feet and legs become colder than the chest area when the diver is in an upright position. This, of course, would occur when the diver is in a horizontal position.

The thermal undergarment should therefore be gas permeable to prevent substantial insulation loss with depth, and relatively incompressible to minimize loss of insulation due to the hydrostatic pressure differential between the diver's chest and feet.

Dry Gloves

An important part of the development program would be the protection of the hands from cold water exposure. Because of the large surface area to volume ratio, the hands cool quickly in a cold environment. Unprotected hands quickly become painful, stiff, and insensitive; in addition, in almost any dive scenario the diver's ability to use his hands is the limiting factor in his capability of accomplishing the mission objective and safely manipulating his life support equipment.

While foam neoprene wet gloves afford some protection, they do have the same disadvantages of wet suits. Bulky wet suit gloves especially hamper manual dexterity. A dry glove with an insulating liner would alleviate many of these problems. A primary area of research would be to develop a secure, watertight connection between the dry gloves and the dry suit. The gloves would have to be capable of being donned and doffed by a diver with no assistance.

Dry gloves with insulating liners require the addition of gas as the diver descends to avoid liner compression and hand squeeze. This is provided by allowing a small amount of gas to escape through the suit wrist seal into the glove. When the diver ascends, the inflation gas in the glove will expand. This gas will not pass back through the wrist seals and must be allowed to escape through vent valves on the gloves.

Buoyancy Controls

It is mandatory that a diver wearing a dry suit have the ability to regulate the volume of inflation gas in the suit. Evaluation of commercial dry suit buoyancy controls (suit gas inlet and exhaust valves) revealed problems of water entering the dry suit and inadequate gas flow characteristics. These problems could degrade thermal insulation and even cause uncontrolled ascents or blow-up situations which are considered to be the most serious safety problem associated with the use of a variable volume dry diving suit.

Inlet and exhaust valves selected or designed for the dry suit system would have to be carefully tested to ensure the diver's ability to operate them. A diver in a flooded dry suit should be able to return to the surface readily in the event of an accident.

Weight Distribution

A dry suit system would pose unusual weight distribution problems. Positive buoyancy produced by an inflated dry suit would require the diver to carry more weight than he would wear with a wet suit.

An inflated dry suit would cause the legs to become buoyant, creating difficulty for the diver in swimming and maintaining a desired attitude in the water. Testing of commercial dry suits indicated that weights should be placed on the legs to counteract the buoyancy.

Various schemes to distribute the extra weight a dry suit diver must carry would have to be tested and evaluated so that the diver would have maximum control and ease of motion.

Diver Urine Collection System (DUCS)

It is a well established fact that immersion and chilling both increase urine production. This is primarily due to the increase in central blood volume caused by the hydrostatic pressure gradient of immersion and vasoconstriction due to chilling. While urine production does not cause any problems in wet suits, it is a hygienic problem in a dry suit; and the moisture degrades insulation. Therefore, a dry suit required development of a urine collection system, particularly for long duration missions.

Prototype urine collection devices were adapted from a design used by NASA on the Apollo missions. The devices would need testing and possible modifications for use in diving.

The dry suit system would be developed as a modular system, but the system as a whole would have to meet functional and operational criteria. Special emphasis was placed on the design of the total system to:

1. Improve mobility and swimmability.

2. Reduce suit leakage.

3. Reduce insulation decay due to suit squeeze and water absorption.

4. Improve diver performance by improving hand warmth and dexterity.

5. Improve diver comfort.

DEVELOPMENT AND TESTING

OUTERGARMENT

Based on findings from tests in the initial program phases, the decision was made to avoid the use of closed-cell neoprene foam for the outergarment, although most commercial dry suits are fabricated from this material.

To select the optimum material, a series of tests was conducted to evaluate the tensile strength, abrasion resistance, tear propagation, and other physical characteristics of various candidate materials. In addition, suits fabricated from these materials were procured and evaluated. Test results are given in Table 4 and test methods are described in Table 5.

Tests conducted by the Department of Kinesiology, UCLA; NCTRF; and by NCSC/NEDU all indicated that materials with a moderate stretch capability permitted much better fit and comfort over the range of diver sizes. This was particularly important since the decision was made to fabricate the suits in a limited number of standard sizes, thereby avoiding the custom fit required for wet suits. Suit sizes were based on anthropometric data obtained from a survey of 157 divers from NAVSPECWARGRU ONE and NAVSPECWARGRU TWO.

Tests revealed that commercially available elastomer-coated fabric suits did not provide enough stretch for adequate diver mobility and comfort. However, a newly developed material did show promise. This material is composed of neoprene foam which had been irreversibly crushed to permanently eliminate all closed cells. The crushed foam is laminated between layers of nylon knit fabric and appeared to be superior in stretch modulus, abrasion resistance, and tear resistance to the other materials considered.

NCTRF tested this crushed foam material for a number of physical characteristics and compared it with characteristics of a neoprene-coated, knitted stretch nylon which met the requirements of MIL-C-23926, Type I, and a commercially available natural rubber coated, knitted stretch polyester.

TABLE 4

TEST RESULTS - DRY SUIT SHELL MATERIALS
(Sheet 1 of 3)

	Neoprene Coated Knitted Stretch Nylon Type I - MIL-C-23926		Natural Rubber Knitted Stretch Polyester	Crushed Neoprene Foam-Nylon Laminate	
	Production 1	Production 2		From 3/32 in Foam	From 1/8 in Foam
Weight, oz/1 sq yd	17.8	17.7	30.8	29.3	30.1
Thickness, in. 1. Overall 2. Coating	 0.031 0.013	 0.031 0.017	 0.044 0.036	 0.065 0.017	 0.075 0.013
Breaking strength, lb/2-inch width wales and courses	141 61	141 51	237 140	280 178	286 196
Elongation, percent wales and courses	203 504	183 944	91 240	222 317	208 314
Bursting strength, lb against coated side and fabric side	164 116	159 127	310 232	against face side 346	351
Hydrostatic resistance psi, against 1. coated side and fabric side number of specimens	59 46	91 74	239 209	against face side 98	90
2. end point of leakage number of specimens	3 of 5; 4 of 5		•		
3. end point--burst	2of5; 1of5	all 5 all 5	all 5 all 5	all 5	all 5

TABLE 4
(Sheet 2 of 3)

	Neoprene Coated Knitted Stretch Nylon Type I - MIL-C-23926		Natural Rubber Knitted Stretch Polyester	Crushed Neoprene Foam-Nylon Laminate	
	Production 1	Production 2		From 3/32 in Foam	From 1/8 in Foam
Water leakage, visual (low hydrostatic)	None	None	None	None	None
Cold crack at -40°F 1. visual	OK	OK	OK	OK	OK
2. hydrostatic resistance psi against coated side and fabric side	84 49	90 70	240 208	against face side 95	93
Adhesion of coating lb/2-inch width	23.1	10.3 + incomplete separation	47.1 + incomplete separation	ply adhesion 56	30
Modulus at 75% elongation in course direction, lb	2.5	1.9	5.9	1.6	1.7
Tension set after 100% elongation course direction, %	17.0	4.0	5.0	14.0	14.0
Flexing resistance, 1000 cycles at 50% elongation course direction 1. visual 2. water leaks	small tear leaks	OK OK	OK OK	OK OK	OK OK

TABLE 4
(Sheet 3 of 3)

	Neoprene Coated Knitted Stretch Nylon Type I - MIL-C-23926		Natural Rubber Knitted Stretch Polyester	Crushed Neoprene Foam-Nylon Laminate	
	Production 1	Production 2		From 3/32 in Foam	From 1/8 in Foam
Abrasion resistance					
200 cycles	surface abrasion of coating	surface abrasion of coating		progressive abrasion of of face of fabric laminate	progressive abrasion of of face of fabric laminate
400 cycles	destruction of coating and fabric	destruction of coating and fabric	surface abrasions of coating only		
800 cycles	-	-			
Base fabric (separated from coating wherever possible--approximate values)					
1. Weight, oz/sq yd	4.2 to 5.2 (specification)	4.2 to 5.2 (specification)	-	face 7.5 back 4.1	face 7.5 back 4.3
2. Wales and courses per inch	36 31	37 28	29 27	face 38 42	face 33 41

TABLE 5

TEST METHODS - DRY SUIT SHELL MATERIALS

Parameter	Method*	
Weight	5041	
Thickness	5030	
Breaking strength	5102	Sample 2-inch width.
Elongation	5102	Sample 2-inch width.
Bursting strength	5120	Run against both face (coated side) and back (fabric side). For laminate run against fabric face only.
Hydrostatic resistance	5512	Same procedure as above. Note if end point was water leakage or burst.
Water leakage	5516	Apply 60 inches water pressure for 3 hours. Note any leakage.
Cold crack	5874	Expose at -40°F for 1 hour. Note signs of cracking, flaking, coating separation, etc. Conduct hydrostatic resistance on exposed sample. See Hydrostatic Resistance above.
Adhesion of coating	5970	For coated fabric. Run wale direction only.
Ply adhesion	5950	For compressed foam laminate. Run wale direction only.
Modulus at 75% elongation	--	Run in course direction. Machine speed 5 inches/min.
Tension set after 100% elongation	--	Same as above. Elongate for 16 hours.
Flexing resistance	--	Run in course direction at 50% stretch for 1000 cycles. Make visual examination and conduct water leakage test as in Water Leakage above.
Abrasion resistance	5306	Use H18 wheels and 500 g load. Adjust cycles for best methods of comparing samples. Observe extent of coating and fabric abrasion.
Base fabric		
a. Weight	5041	Base fabric may be separated from coating by hand or by use of solvent, if possible.
b. Wales and courses	5070	

*Test methods refer to Federal Test Method Standard No. 191.

Prototype outergarments were made from the crushed foam material, and diver-evaluators reported that these suits were more comfortable and permitted a greater range-of-motion than prototype suits fabricated from elastomer-coated fabrics. Neither material provided much thermal insulation because insulation was provided by the undergarment, so there was no preference on a thermal basis.

The crushed foam material was selected for the body of the outergarment, but testing revealed that neck and wrist seals would have to be made of other materials. The crushed foam material was found to take on an excessive permanent set when stretched to 100 percent elongation. After several uses, the neck seal and wrist seals (which were stretched the most) became too loose to prevent water entry or retain suit inflation gas.

Through in-house work and by contract with Battelle Laboratories, Columbus, Ohio, NCSC explored several concepts for improved suit seals. It was determined that closed-cell neoprene foam was the most skin compliant material commercially available for diving suit seals. Closed-cell neoprene foam retains its shape and stretch properties quite well. Latex seals are also effective but are fragile and more vulnerable to degradation from ozone and ultraviolet light.

The crushed foam outergarment was modified to include a 1/8-inch neoprene foam hood with a face seal, a 3/16-inch foam neck seal, and 1/4-inch tapered foam wrist seals. The neck seal was designed to be folded up and then down against the neck when donned, so that increasing internal suit pressure tightens the seal against the neck. The body of the suit was made of 1/16-inch crushed foam. These seals proved to be effective during testing, and were retained during the rest of the system development.

Several entry zipper locations were examined. From previous testing, an across-the-shoulder, water-tight zipper was chosen because it provided the best suit mobility and zipper reliability. This location was chosen despite the fact that a diver would need assistance in closing the zipper (Figure 11.)

The outergarment was designed to fit closely over an undergarment in the crotch and seat area to facilitate swimming and reduce excess buoyancy. Ankle straps, calf restraints, and thigh restraints were attached to the outergarment. These wrap around the legs and are secured with hook-and-pile fasteners. The legs have molded neoprene soles attached to the boot areas. When the restraints are fastened snugly, excess buoyancy is prevented in the legs because they do not balloon when inflated. This had been a problem observed with all the commercial dry suits. Pockets are provided in the calf restraints for weights.

Penetrating the outergarment are an inlet valve and exhaust valve for buoyancy control. The exhaust valve is located on the upper left arm of the suit. The inlet valve, originally located in the left chest area, can also be located on the upper left thigh of the suit (see Buoyancy Controls).

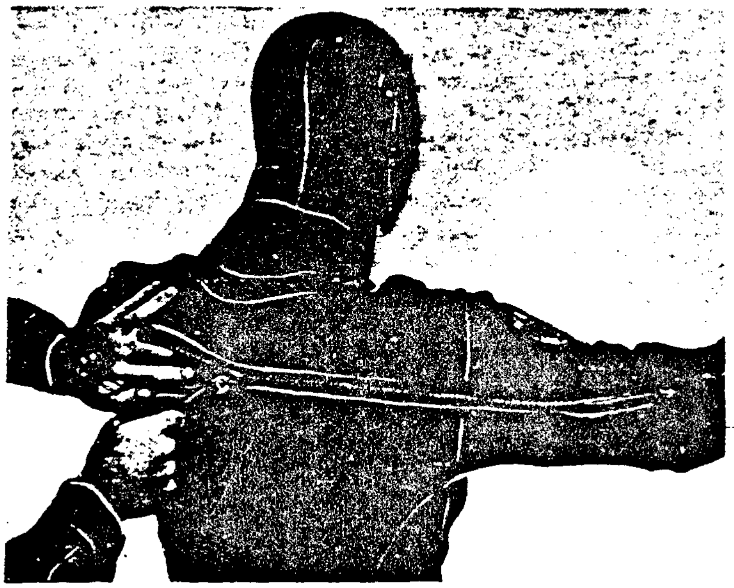

FIGURE 11. CLOSING THE OUTERGARMENT ZIPPER

At each wrist is an elastomer-covered, rigid plastic wrist ring on which the dry gloves seal. The configuration of the wrist ring underwent several changes during the dry glove development (see Dry Gloves).

On each heel of the outergarment is a short strip of nylon pile which mates with a loop of hook fabric on the swim fin strap. When engaged, the assembly secures the fin to the foot. In addition, the loop provides an improved grip when donning and doffing the fins.

After the outergarment configuration had been established of a crushed foam body with closed cell neoprene foam hood, neck seal, and wrist seals, subsequent development and testing produced some changes in the neck seal and boot areas, but only minor changes in the rest of the outergarment. These minor changes primarily dealt with the variable volume controls, suit sizing, dry gloves, weight distribution, and DUCS (see discussions on development of these items).

THERMAL UNDERGARMENT

Since the outergarment provides little thermal insulation for the suit system, the undergarment must provide most of it. Several types of insulating undergarments were tested in the initial phases of the development program but all proved unsatisfactory due to compressibility and, when the garments were wet, degradation of insulating value.

From testing and the analytical thermal model, NCSC had established that an effective insulation material had to allow the inflation gas within a dry suit to freely permeate the material to prevent diving pressures from compressing the material. The material should provide enough insulation to allow construction of undergarments with an overall insulation value of 1.0 to 1.5 clo. Furthermore, the insulation material needed an inherent compression resistance to a pressure of approximately 2 psi that results from the differential pressure head created along the length of the diver's body when vertical in the water. Ideally, the material should be resistant to insulation degradation when it becomes wet.

NCTRF conducted an extensive study on commercially available open-cell polyurethane foams and fibrous polyolefin (polypropylene) batt insulation materials to determine which would be suitable and effective for use in a diver's thermal undergarment.[8] These materials were not being used in commercially available diver's underwear; so for comparative purposes, they were tested against insulation materials in current use.

To establish the range of thermal insulation and compression resistance properties obtainable from open cell foams, NCTRF evaluated over 30 polyurethane foams of different pore sizes, densities, and thicknesses. Low-density polyolefin microfiber batt and insulation materials currently in use in diver's undergarments were tested for the same properties. Major conclusions of the studies included:

1. For adequate compressional resistance to pressures of 2 psi, open-cell polyurethane foams should have densities of 0.12 g/cm^3 or more (thickness loss is less than 30 percent).

2. For maximum insulation values in open-cell polyurethane foams, fine-pore sizes should be used.

3. The maximum density for open-cell polyurethane foams flexible enough to be used in clothing applications should be 0.12 g/cm^3.

4. A fine pore open-cell foam with a density of 0.12 g/cm^3 will meet minimum thermal insulation requirements of 1.0 clo at 2.0 psi with an initial uncompressed thickness of 0.79 cm or more.

5. Even though it undergoes compression to 40 percent of its original thickness at pressures of 2 psi, the microfibrous polyolefin batt with a density of 0.057 g/cm^3 meets the minimum insulation requirement of 1.0 clo when it has an initial uncompressed thickness of 1.18 cm or more because it has a high thermal resistance of 2.11 clo/cm at 2.0 psi.

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[8] Audet, Norman F., Orner, George M., and Kupferman, Zelig, "Thermal Insulation Materials for Diver's Underwear Garment," American Society of Mechanical Engineers publication OED-Volume 6, pages 133-149, December 1978.

6. High density open-cell polyurethane foams and the polyolefin batt were considered superior to all materials in use because of better compressional resistance at pressures to 2.0 psi and of equal or superior thermal insulation resistance when uncompressed.

The results of this investigation were used to select two candidate insulation materials to construct prototype diver undergarments:

1. A 0.128 g/cm^3, 90 pore-per-inch, open-cell polyurethane foam in thicknesses of 0.47 and 0.79 cm.

2. A 0 057 g/cm^3 fibrous polyolefin batt material in thicknessess of 0.82 and 1.63 cm.

These two candidate materials were also tested for their thermal properties when wet. The two materials and a closed-cell neoprene foam wet suit material were submerged in water for 6 hours. The polyolefin batt increased in weight approximately 17 percent due to water pickup; the polyurethane foam showed a weight increase of approximately 750 percent. Thermal properties of the materials at the surface indicate the superiority of the fibrous batt material, particularly when wet (Table 6).

TABLE 6

THERMAL PROPERTIES OF CANDIDATE AND IN-USE MATERIALS IN DIVERS' GARMENTS

Material	Thermal Conductivity (K) Btu/ft-hr-°F		Thermal Resistance (Clo/in.)	
	Dry	Wet	Dry	Wet
Closed-cell neoprene foam	0.030	0.030	3.16	3.16
Open-cell polyurethane foam	0.021	0.121	4.51	0.78
Fibrous polyolefin batt	0.019	0.027	4.98	3.51

Prototype undergarments were fabricated using both candidate materials. The insulation was laminated between an outer layer of nylon taffeta and an inner layer of neoprene-coated nylon taffeta. The outer layer formed a smooth slip surface to facilitate donning the dry suit outergarment over the thermal undergarment.

The inner layer acts as a vapor and moisture barrier to inhibit the infiltration of the diver's perspiration into the insulation. In doing so, it prevents degradation of the suit's insulating qualities due to moisture; it also prevents loss of the heat of vaporization (1000 Btus per pound of sweat) that accompanies perspiration from a diver's body, which can account for a significant heat loss during a long dive.

Beneath the thermal undergarment the diver would wear a moisture-absorbent comfort liner such as cotton long underwear to absorb the sweat which often results during suit donning and heavy underwater work.

Three sizes each of two prototype undergarments were evaluated for range of motion and comfort. The two specific prototypes tested were:

1. 3/16-inch thick polyurethane foam coverall with 5/16-inch thick boots.

2. 0.3-inch thick polyolefin batt coverall with 0.6-inch thick boots.

In addition, a third prototype from the MK 12 SSDS program was included in the evaluation for comparison.

Six subjects performed range-of-motion exercises in long johns (for nude baseline measurements) and in the undergarments. Tests were also performed underwater with subjects wearing prototype undergarments and outergarments.

Test results showed that the polyolefin batt insulation undergarment allowed slightly greater range of motion and mobility than the polyurethane foam undergarment. Diver evaluators reported that the polyolefin batt undergarment was more comfortable than the others tested. The extra thickness of the batt was compensated by its greater softness and flexibility. Both prototypes allowed greater mobility than did the MK 12 undergarment used for comparison.

The superiority of the polyolefin batt undergarment in range-of-motion and thermal insulation (especially when wet) made that prototype the one preferred. Subsequent system tests confirmed the undergarment's ability to provide adequate insulation to a diver for the missions to which a passive system would be applicable.

Further refinements led to an undergarment design which is both comfortable and practical. The material is a microfibrous polyolefin batt with nylon taffeta bonded to the outside and neoprene-coated nylon taffeta bonded to the inside. The garment is composed of three components: jacket, trousers, and boots. The jacket has an elastic stirrup at each hand to aid in donning, and the trousers have an elastic stirrup at each foot. The boots are doubly insulated, and each has a hook-and-pile fastener to secure the boot. The jacket and trousers have plastic zippers and are held together by elastic straps secured with hook-and-pile fasteners.

Five standard sizes have been planned for the undergarment. However, flexibility in fit is allowed by the different size jackets, trousers, and boots which are compatible. A more detailed discussion of this development effort is given in Reference 9.

VARIABLE VOLUME CONTROLS

Buoyancy control of a dry suit system was a problem noted on most commercially available suits. The most common means of inflation was through an oral inflation hose and valve, which also served as the exhaust mechanism. Two commercial suits used separate inlet and exhaust valves, with the inlet valve connected by an inflation hose to a low-pressure inflation source, such as a SCUBA first-stage regulator low-pressure port.

Oral inflation of the dry suit was considered unacceptable for a diver who may make a number of changes in dive depth. In evaluating the commercial suits, the oral inflation valve was replaced with a combination inflation/exhaust valve supplied with air from the first-stage regulator on the diver's open-circuit SCUBA.

During testing, it was observed that the inlet and exhaust controls must be large enough for the diver to operate while wearing gloves. A combined inlet and exhaust valve could be confusing, so separate valves should be provided for inflating and purging the suit. Both should be easy to reach and to operate. In several commercial suits, this was not the case.

Exhaust valve location was found to be important. The lower and more central the exhaust valve location, the more difficult purging was, since the diver had to roll over on his back to completely purge. Some valves also had inadequate flow characteristics. These problems could be a safety hazard during a rapid diver ascent since any inability to properly vent could cause a suit blow-up. An exhaust valve location high on the diver's body was preferred.

One commercially available exhaust valve had a unique feature considered desirable for the system being developed. This valve had an automatic relief with a variable setting. This facilitated setting a specific suit inflation pressure. In addition, it had a manual override which could be used at any time. Pending flow tests on the valve, it was chosen for the PDTPS, with the location to be on the upper left arm of the outergarment. This location allowed the diver to thoroughly purge his suit of inflation gas while ascending vertically in the water. The large override button could be activated by the right hand or by pressing the valve to the diver's head.

The location of the inlet valve was not as important as long as the diver could easily reach the valve. On some commercial suits, the inlet valve was

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[9]Naval Coastal Systems Center Technical Memorandum TM 281-80, "The Development of Thermal Undergarments for Diver's Dry Suit," by M. L. Nuckols, May 1980.

operated by pushing a button which was small and difficult to depress. One commercially available inlet valve was selected for the PDTPS, pending flow tests, because it was fairly easy to operate. Location of the valve on the system being developed was the left chest of the outergarment, accessible to either hand. Later operational tests indicated that this location (with accompanying inflation hose) could interfere with some diving equipment. An alternate location on the upper left thigh was then chosen although the inlet valve can be located nearly anywhere on the outergarment at no additional fabrication cost. The chief criterion for location of the inlet valve is its accessibility to the diver.

The inlet and exhaust valves chosen for use on the system were both subjected to tests of their flow characteristics. NCSC tested the valves and compared their flow characteristics to minimum requirements reached through analytical means. Figure 12 presents a comparison of the flow characteristics of the exhaust valve selected with a widely-used commercial alternative. Both valves were found adequate for diver needs although minor modifications were suggested and tested which would improve the valve flow rates. The valves were found acceptable without modifications for use in the dry suit system.

The valves can be modified when necessary by replacing existing fittings and springs with nonferrous ones. The purpose of these modifications was to allow the valves to pass required magnetic signature tests. The valves, with these modifications, passed magnetic evaluations performed at the US Naval Explosive Ordnance Disposal Facility, Indian Head, Maryland.

An inflation hose connects to a fitting on the inlet valve and runs to an inflation source. The connector at the other end of the hose is compatible with a standard low-pressure port on a SCUBA first-stage regulator. When the suit system is used with a closed-circuit breathing apparatus, a separate source of gas for suit inflation is required. A tab of nylon webbing with a brass grommet is attached to the outergarment at the waist to secure a pouch containing a small, high-pressure cylinder with regulator for independent suit inflation.

DRY GLOVES

Because of their high ratio of surface area to volume, the hands are especially vulnerable to cold water. A moderate amount of manual dexterity is usually necessary for a diver to accomplish his underwater tasks and manipulate his life support system controls.

Most existing diver's gloves are made from closed-cell neoprene foam and insulate in the same manner as wet suits. But when they are thick enough to afford even a minimal amount of thermal protection, their bulk greatly impedes manual dexterity. These closed-cell foam gloves will compress greatly at even moderate depths, losing much of their insulating quality.

A dry glove developed by NCTRF for extreme cold weather use in an air environment was evaluated at NCSC in pool tests and found to provide good

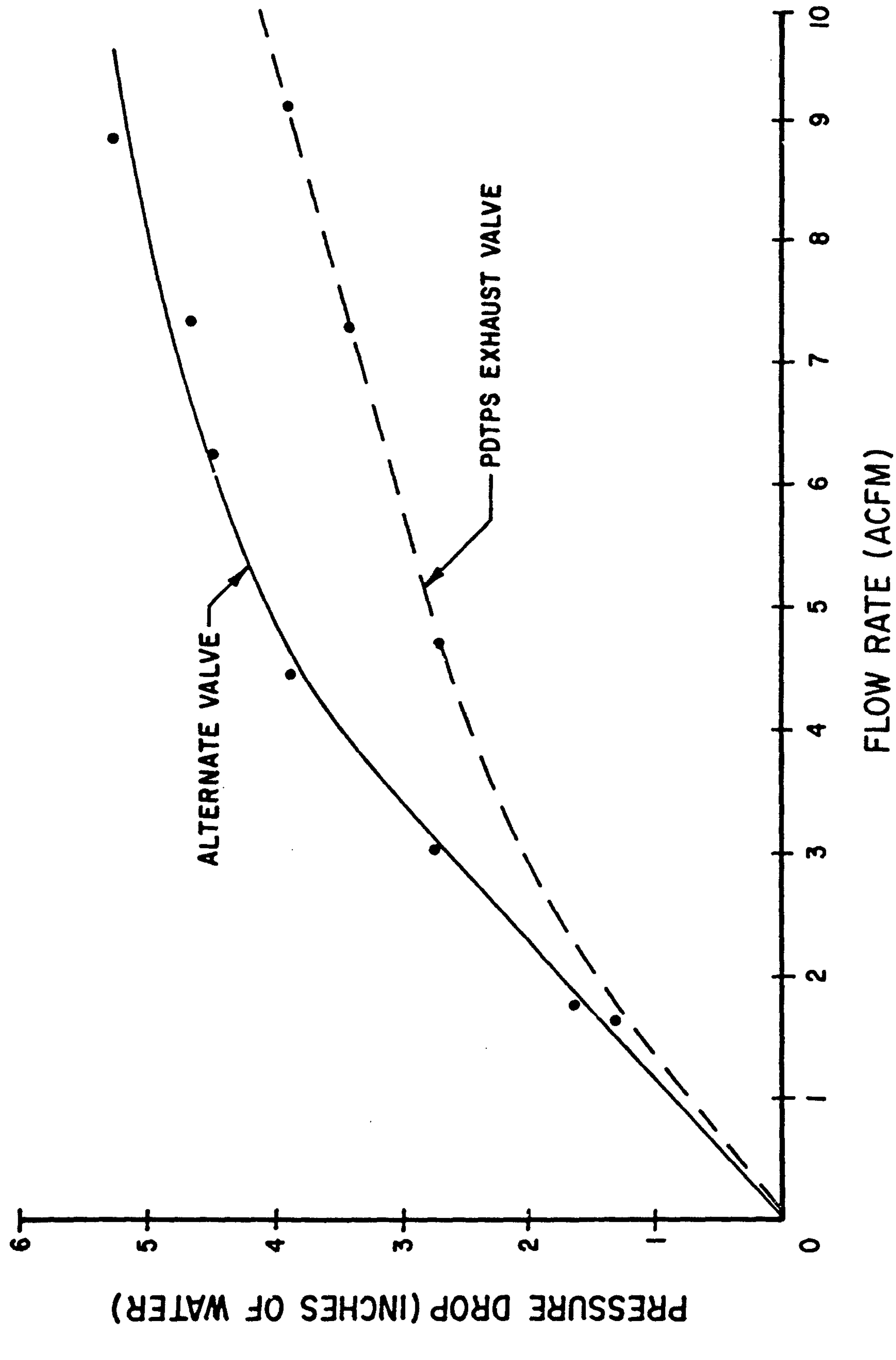

FIGURE 12. FLOW CHARACTERISTICS OF COMMERCIALLY AVAILABLE EXHAUST VALVES FOR DIVER'S DRY SUITS

thermal protection with surprisingly good dexterity. The glove had a water-tight shell made of a neoprene-coated cotton fabric. Insulation was provided by an open-cell polyurethane liner. Initial testing of the glove showed the dry glove provided 40 percent more insulation than a wet glove of similar bulk. Equipment necessary to administer five standard tests of manual dexterity underwater was developed and used to obtain objective information in subsequent evaluation of glove performance.

Since the dry glove selected was not designed for underwater use, a seal between the glove and the outergarment sleeve was required. Many different sealing techniques were developed and tested before a satisfactory seal was found.

For operational reasons, the diver should be capable of donning and doffing the dry gloves without assistance. For this reason, a water-tight seal between the glove and outergarment was attempted with a wrist ring on the outergarment and a elastomer sealing ring on the glove shell. The diver donning the glove would pull the sealing ring over the wrist ring, forming a seal. A major donning problem arose when the second glove seal had to be secured using a gloved hand.

Several configurations of this scheme were tested with different elastomers. When the seal was properly formed, the gloves provided good thermal protection. But the glove seals frequently were dislodged while diving; and the tight seal required made donning difficult and frequently the tight seal was not achieved. When water leaked into the gloves, much of the insulation was lost.

A final configuration of the dry glove has been tested with good results. The shell is made of a mitt portion and upper, or gauntlet, portion. The mitt portion is a neoprene-coated fabric. The attached gauntlet is made of 1/4-inch closed-cell foam with a tough, flexible, Lycra-Spandex fabric bonded to the outside. The gauntlet seals over the elastomer surface of a wrist ring integral to the outergarment. The diver secures the gauntlet over the wrist ring using an elastic strap with a hook-and-pile fastener.

Testing by diver-evaluators at NEDU has indicated that this last configuration is capable of being donned without assistance and will withstand repeated blows by hard objects to the sealing area without leaking.

The glove liner insulating material was changed to a fibrous batt of mixed polyolefin and polyester. This batt provides much more thermal insulation when wet than the urethane foam used previously. It is of lower density than the undergarment insulation and is more compressible, providing greater manual dexterity. A compression resistant quality is not as necessary in the gloves as in the undergarment since the hands are normally used close to the level of the chest where the suit pressure is maintained at local ambient pressure.

One feature incorporated into the early models of the dry glove, and retained without change, is a vent valve on the back of each glove mitt. As the diver descends, the gas in the dry glove is compressed and a loss of thermal protection and dexterity occurs unless gas is added to the glove. This is accomplished by raising the hand and flexing the wrist so that small quantities of gas escape through the wrist seal and into the glove. When the diver ascends, this gas expands but will not pass back through the wrist seal and must be exhausted to prevent loss of dexterity and glove seal failure. The small vent valve mounted on the back of each glove allows the excess gas to escape. The vent valves are one-way flapper valves which require no adjustment and operate automatically. These valves are also necessary to relieve pressure when the diver jumps or parachutes into the water.

WEIGHT DISTRIBUTION

The thermal protection of the passive DTP system is provided by the inflation gas trapped in the thermal undergarment. To be effective as a thermal protection garment, a dry suit system must be inflated so that gas permeates the insulating material, and the outergarment does not unduly compress the undergarment. The result of this inflation is a significant amount of buoyancy. One of the practical problems in the development of the system was to reduce the suit volume that fills with gas pockets which greatly increase buoyancy but add little extra insulation and move about as the diver changes his position in the water. In the commercial dry suits tested, these wandering bubbles of gas were annoying, particularly in the foot and leg portions. In the NCSC developed system, the thigh, calf, and ankle restraints on the outergarment help control this problem. The elastic properties of the crushed foam material are also an important factor in controlling this excess volume.

In the dry suit system, the diver must wear extra weight to counteract the additional buoyancy caused by the inflation gas. One development problem was to distribute this weight in a way which would minimize the amount of weight needed to achieve neutral buoyancy, minimize mobility restrictions, maximize suit swimmability, and ensure adequate weight-ditching capability in case of emergency.

Early testing showed that if weights were placed on the legs to counteract the buoyancy there, suit swimmability was increased. Initially ankle weights were used. These were 3-pound sheet lead strips which were wrapped around the ankles and secured by straps with hook-and-pile fasteners. Subsequent testing indicated that the ankle weights would irritate the ankles during lengthy swims. Weight pockets were then incorporated into the calf restraints. Lead rod or bar weights are inserted into the pockets, then the calf restraint wrapped around the leg and secured with hook-and-pile fasteners. This arrangement affords flexibility in the amount of weight added to the legs and is quite comfortable.

Two other types of weight additions were tested with the passive DTP system. A standard weight belt can be readily ditched in case of emergency, so its use is recommended with the dry suit. However, some divers require a considerable amount of weight; and the use of an integrated diving vest (IDV)* can distribute this weight more evenly. Tests with an IDV with weights placed in the upper pockets indicated that this configuration was good for maintaining a horizontal attitude. In addition, the restraint provided by the vest in the especially buoyant chest area tended to reduce gas volume minimizing the overall weight requirement.

The use of an IDV is not feasible with all life support systems, but testing showed that leg weights and a weight belt should be used for nearly all applications of the dry suit system. For dives where maximum thermal protection is desired, the addition of extra weight permits a greater degree of suit inflation which results in increased thermal performance.

DIVER URINE COLLECTION SYSTEM (DUCS)

Early in the development of the passive DTP system, researchers recognized that some provision would have to be made for the containment of urine. Due to a number of physiological factors, a man produces more urine when in water than he does in a dry environment. For hygienic reasons and to protect undergarment insulation from moisture, a diver urine collection system (DUCS) was developed.

The original prototype DUCS was based on a NASA design used in the Apollo missions. It consisted of a urine pouch, a one-way valve, a latex cuff, and a garment pouch. The urine pouch was made of PVC and included a hook-and-pile fastening device to go around the waist. The garment pouch was a modified pair of shorts with a pouchlike receptacle for the urine container. The urine pouch had a 2-litre capacity, considered adequate for a 6-hour mission.

The original design was modified when testing showed the design to be cumbersome. One design attempted to dump urine directly outside the dry suit without storing the urine. This design included a roll-on cuff connected to a plastic tube with a check valve to deliver urine outside the suit through a dry suit penetration. Divers who tested this design reported uncomfortable back-pressures while urinating.

A final configuration which proved satisfactory to diver evaluators includes a PVC urine collection bag with an improved check valve to which a latex roll-on cuff attaches. The urine collection bag is held at the waist by a belt with hook-and-pile fasteners. For long duration missions, when the urine collection bag is full, overflow can be dumped outside the suit through a plastic tube, with check valve, which delivers urine outside the suit through a dry suit penetration. The bag provides a compliant volume which eliminates the uncomfortable back pressure previously encountered.

*Cordura nylon vest, divers, integrated NSN-1H 4220-01-045-2194.

PERFORMANCE AND OPERATIONAL DEVELOPMENT TESTS

After a functional baseline for the PDTPS had been established, a series of tests was conducted on system prototypes to determine if the system could meet military operational requirements and the performance characteristics listed in Table 3. Test plans and a test schedule were outlined in a draft Test and Evaluation Plan (TEP), first written in September 1978. This TEP was the first of several planning documents written for the purpose of obtaining Approval for Service Use (ASU) of the PDTPS. The TEP was updated several times during the system development program.

MANNED INSTRUMENTED THERMAL TESTS

In order to test the thermal performance of manned PDTPS prototypes, a special instrumentation system was developed at NCSC and NEDU.[10] This testing system provides a more realistic assessment of system thermal characteristics under actual dive conditions than do the instrumented copper manikin tests.

The manned instrumentation system measures skin temperatures, body core temperatures, and heat flow of divers while they conduct dives in a controlled environment. Subjects are instrumented with a heat flow belt system consisting of 12 heat flow and temperature transducers as well as a rectal probe inserted 6 inches (15 cm) into the rectum. All 12 heat flows and temperatures are monitored at regular intervals by a data acquisition system incorporating a HP 9830 calculator. Mean convective heat flow, mean skin temperature, mean body temperature, thermal insulation of the dry suit, and changes in body heat content are computed by the calculator from instrumentation readings at 3-minute intervals during the dive.

After the subject is instrumented, he puts on the comfort liner, thermal undergarment, and outergarment over the heat flow and temperature transducers followed by his remaining equipment. He then enters the water. In the manned instrumented tests of the PDTPS, subjects were tested at NEDU in a fresh water pool which was cooled to approximately 40°F (4.4°C). Subjects then followed schedules of rest and exercise.

The first manned instrumented tests of PDTPS prototypes were conducted May through June 1979. The dive series consisted of twelve 120- to 180-minute air dives by four subjects at 10 fsw (3.05 msw) and sixteen 180-minute air dives by eight subjects at 70 fsw (21.3 msw). Water temperatures for the 10 fsw dives were 38 to 42°F. The 70 fsw dives were performed in the wet pot of the Ocean Simulation Facility during a five-day air saturation dive; wet pot water temperature was maintained at 35 to 36°F.

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[10] Zumrick, John L., LCDR, "A System for the Assessment of Diver Convective Heat Loss," American Society of Mechanical Engineers publication OED-Volume 6, pages 117-132, 1978.

Two types of outergarment prototypes were used in these tests: one constructed of a knitted stretch polyester fabric with natural rubber coating and one constructed of a crushed neoprene foam and nylon knit laminate. The undergarment prototype used polyolefin batt as thermal insulation. Neither system differed in thermal performance, but the crushed foam outergarment was preferred for its superior comfort and swimmability.

Test results indicated that the prototype systems can safely support a working diver for up to 6 hours and a resting diver for up to 3 hours in 35 to 42°F (1.7 to 5.6°C) water. As predicted, depth-dependent degradation of suit performance was not observed as suit insulation averaged 1.0 clo at both test depths. Problems requiring additional design and test effort were encountered with inadequate thermal protection of the extremities, particularly the hands, and inadequate sealing of the dry suit outergarment which allowed considerable amounts of water to enter the suits. The problems encountered led to the development of improved neck and wrist seals and an improved glove design.

Additional manned instrumented tests of prototype systems were conducted in August 1980 at NEDU. The only type of outergarment tested had a crushed foam body. The neck seal and wrist seals were improved designs made of closed-cell neoprene foam. An improved glove design was also used in these tests. The thermal undergarment was similar to earlier prototypes with polyolefin batt as the insulating material.

Eight test dives were conducted. Since earlier testing had indicated that depth did not affect the thermal characteristics of this type of system, all dives were performed at depths of 15 feet or less using air as the breathing medium. Water temperatures ranged from 40 to 41 5°F (4.4 to 5.3°C). Dive durations were planned for 6 hours, and each diver would perform a planned set of manual dexterity tests. Test plans included a series of exercise and rest cycles on an underwater ergometer. Exercise levels would be varied for each diver to simulate different mission work and rest requirements.

In six of the eight dives, subjects completed the 6-hour planned duration, meeting all established thermal criteria. During all of these dives, subjects performing moderate exercise reported few problems and remained reasonably warm and dry. Two divers rested in a metal chair for a 2 1/2 to 3 hours to simulate low-level activity. These divers reported some chilling, particularly in the legs and feet, which disappeared shortly after leaving the chair and assuming a prone attitude.

One dive was aborted after 1 1/2 hours after repeated leaks in the gloves and arms of the suit. The cause of the leaks was determined to be a faulty bond between the wrist rings and the suit sleeves. This was a manufacturing problem, but correct predive testing of the suit and gloves would have detected the leaks. The leak testing procedure for suits should be emphasized in the System Operation and Maintenance (O&M) Manual and particularly before any extensive cold water dive.

In the eighth dive, the suit was intentionally flooded after the subject reached thermal equilibrium; i.e., about 1 hour 15 minutes after dive start.

The suit zipper was fully opened and left open. The diver's reactions and sensor readings were then monitored until he surfaced at 1 hour 42 minutes.

In general, it was concluded that the prototype DTP systems had demonstrated the ability to maintain a diver in an acceptable thermal status for 6 hours in water of approximately 40°F. Average suit insulation exceeded 1.2 clo. Some problems did occur with the dry gloves and their interface with the suit outergarment, and further improvements were indicated in those areas. The considerable improvement in suit insulation value and diver comfort is explained by the modifications to neck and wrist seals which kept the inside of the suits in an essentially dry condition and permitted adequate suit inflation.

OPERATIONAL DEVELOPMENT TESTS

In order to establish that the passive DTP system could meet the operational requirements of diver missions, a number of specific and combined tests were conducted in the field and at test facilities by evaluators wearing prototype systems. These evaluations confirmed the basic thermal design and led to a number of changes which facilitated field use of the system. The final configuration of the suit system therefore underwent substantial testing and evaluation to ensure it met all operational requirements, although the system was not retested for characteristics unaffected by configuration changes.

Testing was performed at several locations in the field and at test facilities.

Field Testing - Panama City

A series of tests was conducted during December 1979 to assess the performance of the prototype of the passive DTP system in special warfare type activities. Although the neck seals still permitted substantial leakage, testing proceeded because the Gulf water temperatures, at 64°F (57.6°C), precluded thermal problems, even in flooded suits. Tests included realistic simulations of three typical SPECWAR activities: (1) long-distance surface swim, (2) long-distance submerged swim, and (3) helicopter cast and recovery. Parachute jumps were scheduled but not accomplished due to weather problems.

The surface and submerged swims, both 2000 yards, were accomplished without difficulty. The surface swim was followed by cast and recovery of the two divers at 10 and 15 knots from an IBS tied alongside a 35-foot utility boat, without problems. The helicopter cast was performed at a nominal 15-knot forward speed 15 feet above the surface. One diver was struck on the forehead by the exhaust valve located on his left shoulder, a result of improper entry attitude which can be prevented with training. Both divers' glove seals separated upon impact with the water; improved seals and glove exhaust valves would prevent this. Recovery was accomplished via Jacob's ladder to the hovering helicopter without incident.

The system was also tested in two Free-Flooding Submersible (FFS) runs of approximately 3 hours each during February 1980 in St. Andrew Bay, Florida. Water temperatures were approximately 42°F (5.6°C). Two divers used suits with improved wrist and neck seals and experienced no leaks. Extensive, repeated suit modifications resulted in seam leakage and leakage around a valve port. However, the divers remained warm and experienced no difficulty with suit inflation affecting FFS trim.

These tests served to finalize the system design baseline for subsequent operational development tests in which both UDT and SEAL team personnel participated.

Field Testing - Brunswick, Maine; New London, Connecticut

System tests and evaluations were conducted by NCSC and NEDU personnel at the Casco Bay Naval Fuel Farm, NAS Brunswick, from 21 July to 30 July 1980. NEDU Test Plan Number 80-28, dated June 1980, was used as a guideline for tests at both sites. Eight swimmer-evaluators and the FFS support personnel were provided by NAVSPECWARGRU TWO. Casco Bay was selected as a test site due to anticipated normal cool air and water temperatures. However, unseasonably warm weather, with air temperatures up to 90°F (32.2°C), caused problems of diver overheating and affected some planned operations. Water temperatures at the surface were in the range of 59°F to 72° (15°C to 22°C) and 53°F to 58°F (11.6°C to 14.4°C) at depths below 5 feet.

The objective of the tests and evaluations was to determine whether the PDTPS satisfies operational objectives in simulated mission scenarios. The compatibility of the system with other diving equipment was an important aspect of the evaluations. Accordingly, the PDTPS was used with the MK 4 life vest, the MK 15 UBA, SCUBA, parachutes, and an FFS. Figures 13, 14, and 15 show a diver outfitted in the PDTPS with a SCUBA, Integrated Diving Vest, and MK 15 UBA. Support equipment included an Inflatable Boat, Small (IBS), a Zeebird inflatable boat (Z-boat), a 21-foot Navy utility boat, a 41-foot Coast Guard cutter, a 42-foot commercial charter boat, and a UH-1 Search and Rescue (SAR) helicopter.

To demonstrate system performance consistent with design requirements (refer to System Design Requirements and Table 3), the PDTPS was to be evaluated in the following operations:

1. Long-Distance Surface Swim
2. Long-Distance Submerged Swim
3. High-Speed Boat Cast and Recovery
4. Parachute Jump
5. Helicopter Cast and Recovery
6. FFS Runs
7. IBS Paddle

Procedures and results for each test are described in the following paragraphs.

FIGURE 13. DIVER IN PDTPS WITH SCUBA

FIGURE 14. DIVER IN PDTPS AND INTEGRATED DIVING VEST

FIGURE 15. DIVER OUTFITTED IN PDTPS AND MK 15 UBA DONNING FULL FACE MASK

Long-Distance Surface Swim. Eight divers entered the water approximately 2 miles from the staging area and swam back. Only ankle weights were used. The air temperature was approximately 80°F (26.7°C) and the surface water temperature was approximately 70°F (21°C). Problems experienced were overheating and minor difficulty moving the arm forward while performing the side stroke. A subsequent swim without the thermal undergarment was performed with no problems, the long john comfort liner affording adequate chafing and thermal protection for the relatively high water temperatures.

Long-Distance Submerged Swim. Although the test plan called for use of the MK 15 UBA in this swim, operational difficulties and diver inexperience with the rig resulted in the use of SCUBA for a total of twenty 4000-yard (3658 m) swims at depths not greater than 30 feet (9 metres). On three occasions, suit inflation hoses became disconnected; but all were reconnected by the divers without difficulty. Divers again complained of lack of mobility in the arms and shoulders and difficulty reaching the reserve supply valve. Initially, divers complained of a pressure point on each ankle created by the 3-pound ankle weights. At the divers' suggestion, subsequent swims were performed with ankle weights fastened underneath the calf restraints with the existing ankle weight strap; and no further problems were experienced. Some divers complained of suit fit, particularly in the boots. This was considered to be a result of manufacturing error, though other fit problems could require sizing changes.

High-Speed Boat Cast and Recovery. Using the 41-foot Coast Guard Cutter with an IBS attached to the port side, seven divers were cast at approximately 100-foot (30.5-metre) intervals and recovered using the snare. This procedure was repeated four times at speeds ranging from 8 to 14 knots. The cast of a diver during this operation is depicted in Figure 16. On the first cast one exhaust valve was broken off by contact with the snare. The force of the water on cast rolled back the upper portion of the glove, separating the seal and causing glove leakage. Design changes to correct these problems were indicated by this test.

Parachute Jump. Four parachute jumps were accomplished from altitudes of 1200 to 1500 feet (366 to 457 metres) with helicopter air speed of approximately 70 knots. Water impact was uneventful with no suit leaks reported. The upper portion of some glove seals was pulled down while divers doffed the parachute harness and manipulated the lines to collapse the parachute in the water. Several divers complained that the location of the exhaust valve impeded doffing the harness; two complained of a lack of upper arm and shoulder mobility and inability to reach the steering toggles. Four remaining scheduled jumps were cancelled due to fog. Divers wearing the PDTPS and parachute gear are shown in Figure 17.

Helicopter Cast and Recovery. Two lifts of four divers each were performed for a total of eight casts and recoveries. Altitude of the helicopter was approximately 15 feet (4.5 metres) and speed approximately 15 knots. All divers successfully climbed a Jacob's ladder back into the aircraft (Figure 18). Due to improper entry attitude, upon impact with the water two divers were hit on the head by the exhaust valve (located on the

Figure 16

FIGURE 16. HIGH-SPEED CAST OF DIVER FROM IBS

FIGURE 17. DIVERS EQUIPPED WITH PARACHUTES OUTFITTED IN PDTPS

Figure 18

FIGURE 18. HELICOPTER RECOVERING DIVER USING JACOB'S LADDER

left sleeve); but none were injured. The divers agreed that this problem could be eliminated with proper training. Nearly all divers complained of inadequate arm mobility, which made climbing the Jacob's ladder difficult. In several cases, the upper part of the glove seal was rolled back upon impact with the water, and the glove seal separated from the wrist ring. Need for a positive wrist seal was again apparent.

FFS Runs. Two attempts were made by divers outfitted in the PDTPS and MK 15 UBA to complete a Free Flooding Submersible (FFS) run. Both were aborted due to operational difficulties with the FFS, one after approximately 6000 yards and the other after approximately 2000 yards. During these two aborted runs, the divers were in the water a total of 4.5 hours. Both divers had difficulty getting suit inflation to their legs and experienced some chilling there. One diver complained of chafing around the neck and neck seal leakage, a result of the head position required during FFS operation.

A fit check with the PDTPS and MK 15 UBA was conducted at the staging area with the FFS barely submerged, supported by a crane. Pony bottles were not attached to the suit to allow a more convenient placement within the boat. Both divers were able to get into the FFS, close the hatches, and manipulate the controls, but with some difficulty. Neither diver could reach the MK 15 bypass controls, and both felt very crowded within the boat.

IBS Paddle. Relatively high air temperatures increased the probability of extreme overheating in divers paddling a small inflatable boat, and the operation was not conducted.

Data Collection. During all operations, records were kept on each diver-evaluator noting the type of operation, dive conditions, problems encountered, and pertinent facts about the diver. Divers and tenders were given evaluation forms on which they evaluated the PDTPS in 20 specific areas by assigning scores of 1 - Unacceptable, 2 - Poor, 3 - Acceptable, 4 - Good, or 5 - Excellent. Each mean rating obtained was then weighted according to the diver-evaluator's experience. The weighted mean rating given by the divers for the Overall Evaluation question was 3.593. The weighted mean of all responses by the tenders was 3.586.

Diver-Evaluator Comments. Individual and group debriefing focused on suit features and possible improvements. Some specific modifications were suggested by the diver-evaluators; based on these suggestions and prior test results, minor changes were made in the suit system which were intended to resolve the problems encountered during testing:

1. Replacing snaps on the undergarment with hook-and-pile fasteners.

2. Offer the outergarment in a wider range of sizes. Offering both a regular and long in each size was expected to alleviate the problem of insufficient arm and shoulder mobility experienced by some divers.

3. Change the location of the inlet valve to a location more suitable for the specific diver/suit application.

4. Use calf weights instead of ankle weights.

5. Change the handle on the inflation hose quick-connect fitting to eliminate protrusions which result in accidental disconnection.

6. Improve the glove configuration to eliminate problems of glove seal leakage experienced with water impact.

7. Allow more training time for divers, particularly in-water familiarization.

In a meeting on 23 October 1980, representatives from NCSC, NEDU, Special Warfare, and NAVSEA-OOC agreed to focus further operational development testing on special warfare applications and attempt to optimize the system for the FFS operator. Exercise Brim Frost, scheduled for late January 1981 at Kodiak Island, Alaska, would be an opportunity to demonstrate the usefulness of the system for FFS applications in a typical cold environment.

The suggested changes listed above were incorporated, along with other system modifications, into a new configuration to be used for the Kodiak Island tests.

Interim testing was conducted at Whidbey Island in support of this goal and is described in the following section.

Prior to the above test operation, considerable leakage through the seams in the torso portion of the outergarment had been experienced and the development of a new seaming technique was initiated. While this development was in process, the existing suits were modified to prevent seam leakage by the installation of seam tape on the inside of the seams in addition to that already present on the outside. In order to follow the schedule, the modified suits were used in the Maine tests. The increase in stiffness produced by the double taping technique was not really appreciated until suits manufactured by the newly developed seaming technique were received. Many of the comments on the lack of upper torso and shoulder mobility are believed due to this factor. Subsequent tests have shown a significant improvement in mobility and ease of motion.

<u>Range-of-Motion Tests - Navy Experimental Diving Unit (NEDU), Panama City, Florida</u>

Following field tests in Casco Bay, range-of-motion tests were conducted at NEDU to evaluate the degree of restricted mobility experienced by a diver wearing the PDTPS. The performance criterion, as specified in the Test and Evaluation Plan, is a minimum 85 percent of nude mobility.

On 3 September 1980, three test subjects were photographed performing nine different movements, first wearing only long john comfort liners to establish a baseline measurement. The subjects were then photographed performing the same movements dressed in the full PDTPS.

Measurements were made using slide projections to compare nude subject movements with movements of subjects wearing the PDTPS. The suit afforded a mean percent of nude range of motion of 90.1 percent, exceeding performance requirements.

Rapid Compression and Decompression Tests - NEDU, Panama City, Florida

The PDTPS was subjected to compression rate tests in the NEDU Portable Recompression Chamber to evaluate the system's ability to compensate for rapid changes in ambient pressure. On 30 September 1980, a series of three tests were performed with the chamber pressurized and depressurized to simulate diver descent and ascent. The diver had to maintain proper suit inflation at the various rates of travel.

Suit inflation was maintained in all three runs without difficulty, and system capability for rapid compression and decompression was demonstrated to be the maximum allowable for Navy divers: 75 ft/min. compression rate and 60 ft/ min. decompression rate. This exceeds the performance criteria specified in the Test and Evaluation Plan.

Field Testing - Whidbey Island

The purpose of these exercises, conducted at NAS, Whidbey Island, Washington, was to determine the practicality of using the PDTPS with the FFS and to provide training for FFS operators from UDT-12 in preparation for exercise Brim Frost. The PDTP systems used for this activity were the same units used at Casco Bay in July.

Two FFS platoons participated in these exercises. Approximately 29 manhours of FFS operations were accomplished. Surface water temperatures remained between 39 and 42°F (4 and 5.5°C), and air temperatures ranged from 27 to 50°F (3 and 10°C). Dive time during several FFS operations was limited by the safety boat's ability to operate in the surface chop and not by the thermal status of the FFS operators.

The one occasion on which an operator experienced thermal problems was caused by water entering at the zipper opening. The zipper slide had been accidentally displaced. To prevent recurrence of this problem, suits were modified to provide a strap with hook-and-pile closure to cover the slider in the closed position (Figure 19). Additional minor modifications of the suit were indicated during these exercises and are described in the following paragraphs.

Buoyancy in the upper torso of the suit made it difficult for operators to lean forward to operate FFS controls. This problem was resolved by using modified integrated diving vests under the MK 4 life preserver, thus restraining the upper portion of the suit.

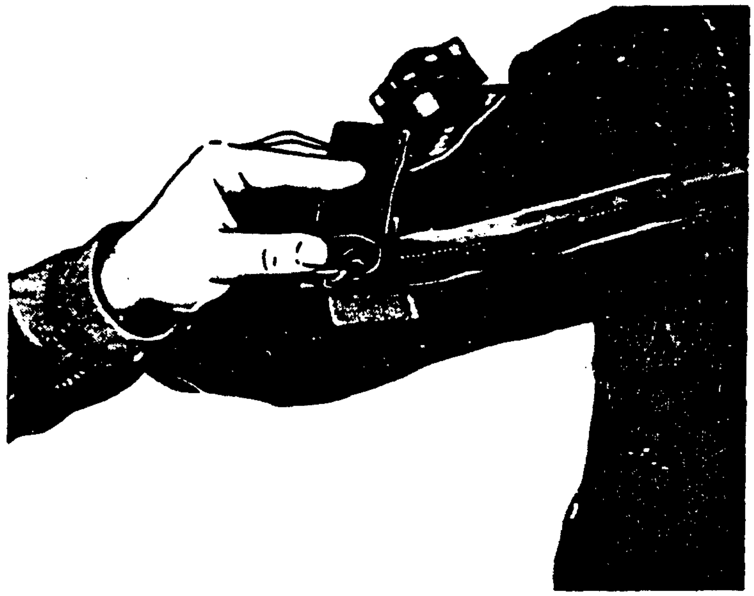

FIGURE 19. FASTENING ZIPPER TAB COVER STRAP

The incidence of damp glove liners was reduced by modifying the glove vent valve with insertion of a disc of open-cell foam under the cover to increase the cracking pressure of the valve.

Also, it was determined that the 1.5-litre bag capacity of the DUCS was inadequate for long dives. A dump line with a check valve, penetrating the suit in the hip area, was recommended since there is insufficient room within the suit to accommodate a larger collection bag.

To reduce tears in the wrist seals and facilitate the don and doff procedure, it was decided to reorient the weave of the nylon fabric to improve tear strength, change to a 3/16-inch material to reduce stretch modulus, and to make the wrist rings slightly elliptical rather than round.

The suit inlet valve was relocated high on the front of the left thigh due to difficulty experienced by diver-operators in operating the valve when outfitted in an IDV, a MK 4 life preserver, and a MK 15 UBA.

The arctic face protector and polyolefin cap were also evaluated during this activity. Both were rated effective and enthusiastically accepted by the divers.

Exercises at this site increased confidence in the capability of the PDTPS to function effectively in an operational environment.

Positive Buoyancy Tests - NEDU, Panama City, Florida

Prior to FFS operations scheduled as part of the Kodiak Island tests, a test was performed at the NEDU Ocean Simulation Facility Test Pool to determine if the PDTPS offered sufficient positive buoyancy to support diver free ascent.

Two divers were outfitted in the PDTPS, Integrated Diving Vest, SCUBA (bled down until neutrally buoyant), weight belt, and maximum calf weights. Fins and life jackets were not worn in order to better approximate conditions of an FFS operation. After intentionally flooding their suits, the divers dropped their weight belts and attempted to surface. Both kicked to the surface with ease, demonstrating the inherent positive buoyancy of the polyolefin batt thermal undergarment material. In the unlikely event of simultaneous PDTPS floodout and MK 15 UBA and MK IV life jacket failures, a diver may exit an SDV and ascend safely by dropping his weight belt.

Field Testing - Kodiak Island

The objective of this activity was to facilitate special warfare missions during exercise Brim Frost and further assess system performance in simulated scenarios. Five systems with a new configuration outergarment were used, and three systems of the prior configuration were taken as spares, together with various accessory items. The new outergarment configuration incorporated modifications made after testing at Casco Bay and Whidbey Island: improved seaming technique, redesigned wrist seals, a redesigned foot and ankle restraint area, incorporation of pockets for the ankle weights in the calf restraints, tall as well as regular sizes, and relocation of the inflation valve to the top of the left thigh. Figure 20 shows the positioning of weight pockets underneath the calf restraint. Gloves with a new seal configuration were provided in addition to units of the prior configuration. Polyolefin batt caps and glove liners, face protectors, and urine collection systems with overboard dump lines were included as accessories for extremely cold water.

Surface water temperatures of 36°F to 39°F (2.2°C to 3.8°C) and air temperatures of 25°F to 45°F (-3.9°C to 7.2°C) were observed during this period with colder water temperatures reported, but not measured, during submerged operations. A total of 11 1/2 hours of PDTPS and FFS runs were accomplished with no unacceptable levels of cold stress or reports of inadequate performance due to the cold water. During the longest operation, the FFS pilot and navigator spent approximately 5 hours in an estimated 34°F (1°C) water with no problems.

Although the system was intended for use only by the five FFS operators in the second platoon of UDT 12, three SEAL personnel were also trained and equipped to use the system due to inadequacy of their own thermal gear. A 5-hour SEAL and FFS operation was completed by two divers involving insertion and recovery of the SEALS and their weapons from the FFS landing at a rocky beach area and pitching a four-man tent. No major problems with the PDTPS were encountered in this operation.

FIGURE 20. DIVER INSERTING WEIGHT INTO WEIGHT POUCH

However, two minor equipment problems were observed which would require further system modification. The new configuration boots did not provide adequate traction on ice, snow, and rock; and the diver's heels tended to slip out of the boot. A design change to provide a harder sole with tread and a relocated ankle strap was indicated. The glove seal configuration allowed only a limited number of uses before the hard vinyl edge of the wrist ring caused ruptures in the neoprene foam seal. A design change covering the vinyl wrist ring with large diameter dual O-rings has corrected the problem.

The system was considered ready for Approval for Navy Use, lacking only the correction of these two problems and testing and evaluation of the changes.

The composition of the boot sole was changed to a more rigid material which prevented the previously experienced problems of divers' feet slipping out of the boot. Tread was also added to improve traction. The glove was redesigned to feature an O-ring in place of the vinyl wrist ring and a gauntlet made from 1/4-inch lycra-spandex neoprene. The durability and watertightness of the glove interface with the outergarment was tested on 4 June 1981 in the OSF pool at NEDU. After conducting a static test of the gloves, checking for pinhole leaks, the diver entered the pool, swam for 15 minutes, and subjected the glove gauntlet area to a series of forceful blows against the pool bottom, a steel pipe, and a steel stud. This exercise was repeated twice, with a 10-minute swim between each repetition resulting in a total of 90 blows. No gauntlet failure occurred. An additional 150 in-water and 50 out-of-water blows were administered before leaks were noted.

CONCLUSIONS

Since October 1980, the evaluation efforts described in this report have been directed toward application of the system to solve thermal protection problems of the SPECWAR operator, considered at that time to be the most critical. Evaluations for this application have been completed and the PDTPS is expected to provide adequate protection for the long cold dives.

Other Navy diving activities may benefit from a system that eliminates much of the discomfort involved in cold water dives. These applications can best be identified by training a small group of divers in the use of the PDTPS and monitoring their performance of typical activities while using the system. During this process, most problems that arise can be resolved, and optimum use of the system in the particular application determined. Evaluations of Explosive Ordnance Disposal (EOD) and Underwater Construction Team (UCT) applications of the PDTPS are scheduled to begin during February 1982.

SEALs using the system in the Kodiak Island evaluations experienced restricted mobility during the land portion of the operation. Because the system outergarment prevents exchange of gas with the environment, divers engaged in strenuous land operations also experience serious overheating. However, the PDTPS thermal undergarment alone can provide a useful amount of insulation in a land environment and, supplemented with a coverall windbreaker and additional zippered openings for improved ventilation, can provide thermal support to the wearer over a wide range of activities and ambient temperatures. Thermal analysis predicts acceptable diver performance in an air temperature of -40°F for periods of 2 hours at rest and more than 6 hours when walking at 4 mph. SEAL use of the PDTPS system and undergarment for water and land should be studied.

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